CHAPTER 16

Economic Justification for Industrial Complexes

Section One

Changing from a "waste-treatment" to "waste-utilization" culture involves overcoming many obstacles. The most important of these is proving to industry that by using an environmentally balanced industrial complex (EBIC), production dollars spent and society's dollars used will be lower. Even then, changes will come slowly. Human nature seems to be comfortable with tried and proven practice, while on the other hand, it abhors changing to an unknown one.

In the long run, history has shown that if we can "build a better mousetrap" at less cost, eventually industry will follow like sheep in the field. It is not within our ability to alter human nature, but we as engineers and scientists can show that the economics of production and conservation of natural resources favor the EBIC approach.

Industry is—and always was—in business to make a profit, and the more profit the better. This is not to say that industry does not recognize and is even sympathetic to the environmental cause, but in its eyes, the bottom line comes before any other consideration. Industry believes that it must concentrate on the bottom line to "stay in the game." And "staying in the game" is absolutely essential. It also has become increasingly aware that reusing water—a valuable diminishing and costly resource—is as important as reusing wastes.

I present one recent (1999) decision made by industry to substantiate the aforementioned principle. The College Retirement Equities Fund (CREF) was established and continues today to invest teachers' retirement money in stocks of industries to produce the greatest growth in profit (the bottom line). A group of CREF participants presented a proposal in November 1999 to the board that it divest itself of its holdings in a particular metals-producing industry stock. The participants' proposal was based on the fact that the industry "created and continues to pose unreasonable or major environmental, health, or safety hazards with respect to the rivers that are being impacted by the tailings, the surrounding terrestrial ecosystem and the local inhabitants."

CREF's board rejected the proposal, saying that "were we to divest from a specific company because some participants object to that company's environmental or social record, there would be no reason why a multitude of such types of requests could not be made." That was CREF's reasoning, but here is what lies behind that reasoning. It continued to state, "It would be difficult to fully consider those requests and run an effective investment program for participants who wish their investments to be based primarily upon financial analysis." In other words, money once again drives decisions and once again even at the expense of the environment, which belongs to everybody.

Manufacturing is and will continue to be a vital ingredient in the U.S. economy. Economist Joel Popklin ("Manufacturers warn of impact of plant closings" 2003) supports this conclusion by asserting that manufacturing spawns more additional economic activity and jobs than any other economic sector; each $1 of final demand for manufactured goods, for instance, generates an additional $0.67 in other manufactured products and $0.76 in products and services from nonfactory sectors.

The concept of EBICs was originally proposed for the pulp and paper industry by Nemerow et al. (1977). In the next 23 years, we published many papers describing potential industrial complexes for a number of other industries. Most of these are described in Nemerow (1995).

Rationale for EBics

The field of industrial waste treatment as practiced from the 1940s through the 1980s is now evolving from treatment to waste utilization. Society is calling for lower manufacturing costs along with less environmental degradation. The use of EBICs is not only the logical answer, but the only rational response to society's demands. This system reuses one plant's waste as another's raw material, thus simultaneously reducing raw feed costs and eliminating waste-treatment costs. However, the EBIC system depends on the inclusion of compatible industrial plants. Such a system completely changes our concept of industrial manufacturing. No longer should we locate industrial plants based solely on the economic marketability of our product, but we must consider the usefulness of wastes as raw materials for the ancillary plant. To discharge wastes untreated or partially treated into the environment is no longer an alternative. And, to completely treat the same waste before discharge is too costly for both the industry and society. Simple logic dictates that this waste be utilized directly by another manufacturer to save operating capital for the plants while improving the quality of the receiving environment for society. When industry also reuses water and wastes, it satisfies another of its objectives as well as that of environmentalists.

In the past, industry was more concerned with production problems and costs at a particular site rather than importation of raw material costs. This is no longer the case. When production costs are competitive, industry is concerned with importation costs of its raw materials. As an example of a decision involving these specific costs, Tyson Foods ("Plant closing shows" 2002) "company officials say they will shift production of its bacon brands, which include Thorn Apple Valley and Colonial, to more modern plants closer to its suppliers in the Midwest . . . Tyson says it isn't sure how much money the move will save, but it is clear that the cost to this town (Holly Ridge, North Carolina) is huge."

The World Bank has indicated its worldwide support for industrial environmental protection—indirectly a stimulus for our environmental complex principle. A group of very large banks—such as Citigroup, ABN-AMRO, and Barclays—has announced that the banks will finance large industrial projects through the World Bank after applying strict (but voluntary) environmental standards (Phillips and Pacelle 2003). This policy should provide impetus for industries—especially in developing countries—to utilize concepts similar to the EBIC to economically avoid environmental pollution.

Fertilizer and Cement Production

In conventional practice, phosphate fertilizer and cement are manufactured as shown in the simplified schematic form in Figure 16.1. Three major wastes impose environmental damage on the surroundings. Two of these wastes originate in the fertilizer plant: (1) phosphate rock slime wash water and (2) phosphogypsum sludge waste. The first comes from washing the mined rock free from its varied impurities; the second arises from treating this washed and crushed rock with sulfuric acid, resulting in a calcium sulfate sludge (i.e., phosphogypsum). The third waste leaves the cement plant as dust, both raw material and kiln-type. The former comes from moving raw materials around the cement plant, whereas the latter results from burning the raw materials at very high temperatures.

Three distinct types of damage costs occur when industrial wastes such as these are discharged into the environment:

1. Primary costs to the industry itself, resulting in direct costs
2. Secondary costs to the people surrounding the plant, resulting in indirect costs
3. Intangible costs affecting society as a whole, which are more difficult to quantify, resulting in intangible costs

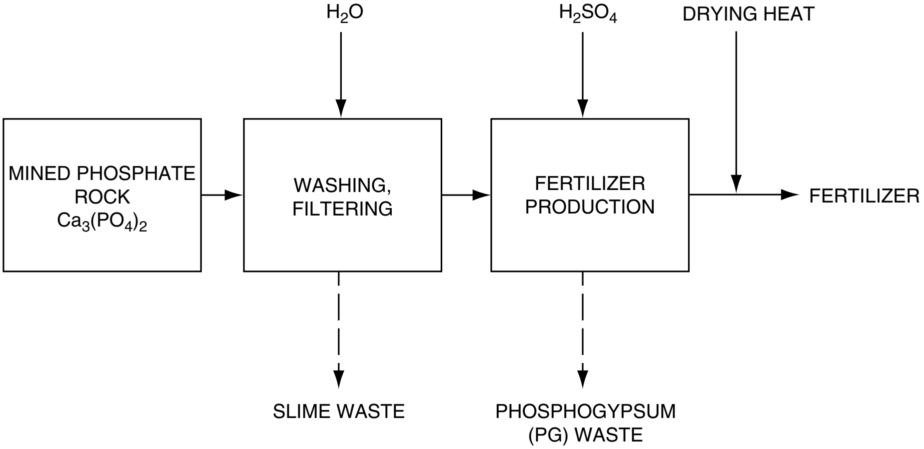


FIGURE 16.1. Mass flow diagram of a free-standing fertilizer plant.

TABLE 16.1
Comparison of Real Production Costs (1995 Dollars) of Free Standing Fertilizer and Cement Plants with EBIC Costs (1995 Dollars) per Ton of Fertilizer

Industry	*Real Cost Includes 3 Damage Costs*	*EBIC Cost*	*Savings in Production Costs When Using EBIC*	*% Savings due to EBIC*
Fertilizer	$245.76	$183.95	$61.81	25
Cement	$67.09	$34.00	$33.09	49

When these three costs are identified, totaled, and added to typical plant production costs, we obtain the real cost of manufacturing a product.

In a research project with these two industries, these costs were identified as shown in Table 16.1. More specifically, the damage costs identified for these two industries were attributed to the following:

1. Unsightly collection and storage of the voluminous sludges on increasingly valuable lands.
2. Leaching of contaminants from the sludge piles or stacks, which adversely affect drinking water and fish downstream.
3. Grinding and burning dusts from the cement plants affect all three environments.

Direct reuse of phosphogypsum and slime sludges in the cement plant within the complex and reuse of the dust by an adjacent fertilizer plant will lessen or eliminate all damage costs from these plants (as shown in column 3 of Table 16.1). A clean environment surrounding the plants will also be achieved (as depicted in Figure 16.2).

Case Study of Economic Proof of Industrial Complexes

Section Two

Fertilizer and Cement Plants: EBIC

In this section, I show that it is substantially less costly to produce two industrial products and reuse all wastes within one complex than to produce the same products at separate locations and discharge the untreated wastes to the surrounding environment. The original researchers of this project (Krishnan et al. 1996) have attempted to use real

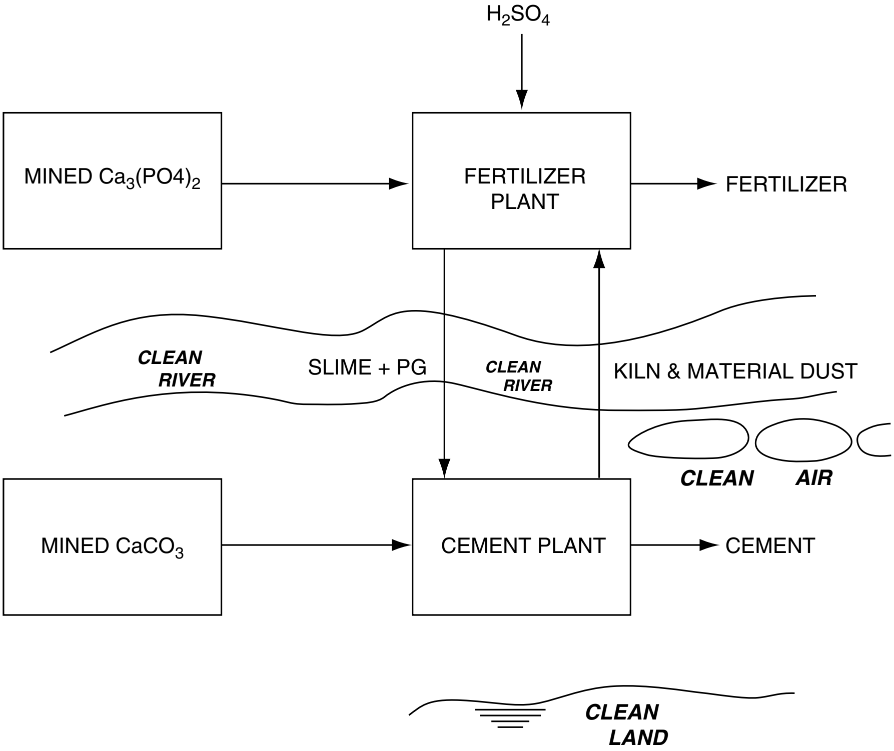


FIGURE 16.2. Clean environment surrounding the plants.

data to put a monetary value on the indiscriminate and wanton discharge of these plants' production wastes into the environment. When this value is added to the manufacturing costs of the two products, the real total production cost becomes 37% higher than that of the industrial complex.

Introduction

Industrial complexing is an innovative attempt to improve environmental quality—as I have argued many times in this text thus far—while lowering production costs. The ultimate goal of both environmental and production engineers is to attain zero pollution and minimum manufacturing cost. Before reaching this goal, industry must include all environmental damage costs—direct, indirect, and intangible—as part of the cost of manufacturing.

In this section, I attempt to measure all the environmental damage costs, add them to typical production costs, and obtain true and real costs of manufacturing a product. When armed with these true costs, industry can decide whether to cease damaging the environment by using EBICs.

Fertilizer and Cement Production

In conventional practice, phosphate fertilizer is manufactured as shown in Figure 16.1 and in the simplified schematic form in Figure 16.3. The two major wastes impose environmental damage on the surroundings. In a similar fashion, cement is manufactured as shown in Figures 16.3 and 16.4. Likewise, its two major wastes cause degradation of the air surrounding the plant.

Figures 16.2 and 16.5 present basic schematics of fertilizer and cement plants EBIC. All four wastes are reused. Some raw materials are substituted by these wastes. Transportation of some raw materials is eliminated, resulting in cost saving. This complexing system thereby reduces production costs even without considering the benefits of abating environmental damages.

Environmental Consequences of Complexing

Two significant types of damage caused by phosphate fertilizer plants' phosphogypsum wastes include:

1. Unsightly collection and storage of the voluminous sludges on increasingly valuable land
2. Leaching of contaminants from the sludge piles or stacks, which adversely affects drinking water and fish downstream

Direct reuse of phosphogypsum and slime sludges in the cement plant within the complex can eliminate the aforementioned damages.

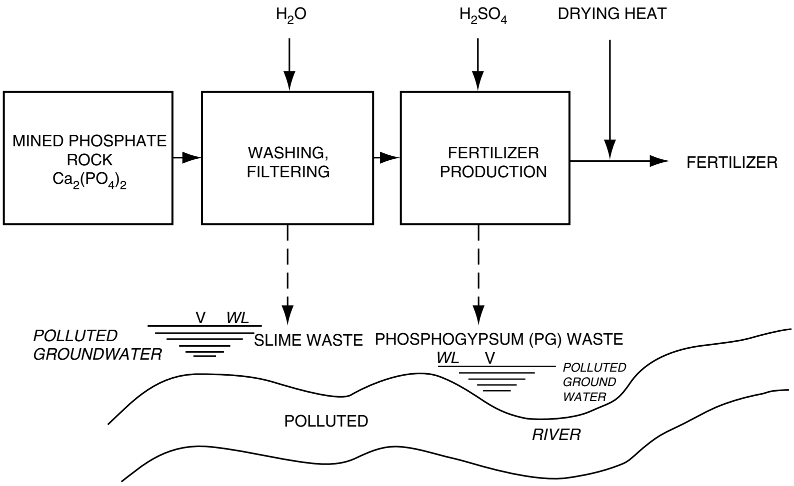
In addition, the dust reaching air around cement plants—from both the grinding and the burning operations—damages the environment. Direct reuse of these dusts by an adjacent fertilizer plant will reduce damage costs from them (see the schematic configuration shown in Figure 16.3).

Environmental Damage Costs

Three types of environmental damage costs result from industrial wastes. The three categories of benefits accruing to society from using the environmental complex principle are presented here (Nemerow and Agardy 1998a).

1. Primary benefits: those affecting the industrial plants themselves, resulting in direct costs.
2. Secondary benefits: those affecting the people surrounding the plants, resulting in indirect costs.
3. Intangible benefits: those affecting society as a whole and those that are difficult to quantify, resulting in intangible costs.

When costs are tied to these benefits and added to normal plant production costs, one obtains the real cost of manufacturing a product.



Mass Flow Diagram of a Free-standing Cement Plant

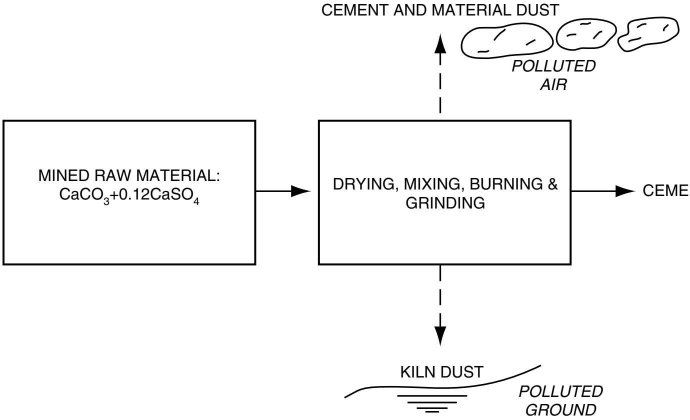


FIGURE 16.3. Free-standing cement plant.

Real Production Costs

When a phosphate fertilizer plant is located alone, its production costs include the usual operation costs: maintenance, materials, and labor (Fc), the direct costs of required waste treatment (Fwt), the indirect costs of environmental damage to nearby owners (Fnd), and the intangible costs of environmental damage away from the plant and to the public at large (Fxd). In summation, the real production cost (Fr) becomes

$$\mathrm{Fr} = \mathrm{Fc} + \mathrm{Fwt} + \mathrm{Fnd} + \mathrm{Fxd}. \tag{1}$$

Each of the quantities in Equation (1) will now be identified for the fertilizer plant.

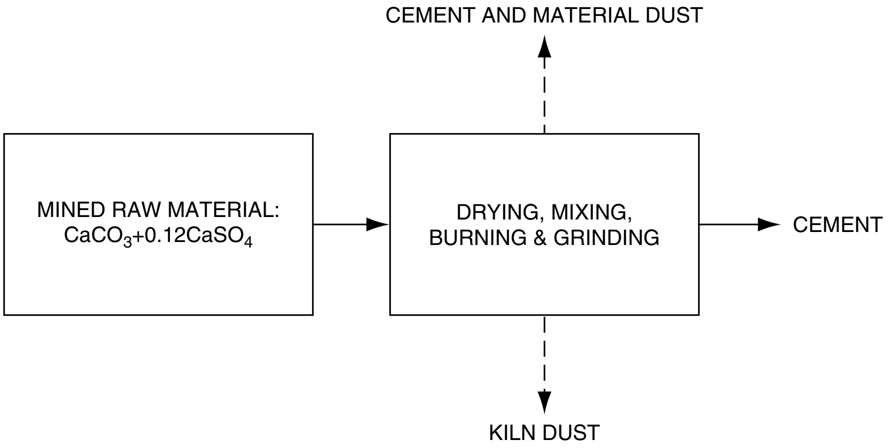


FIGURE 16.4. Mass flow diagram of a free-standing cement plant.

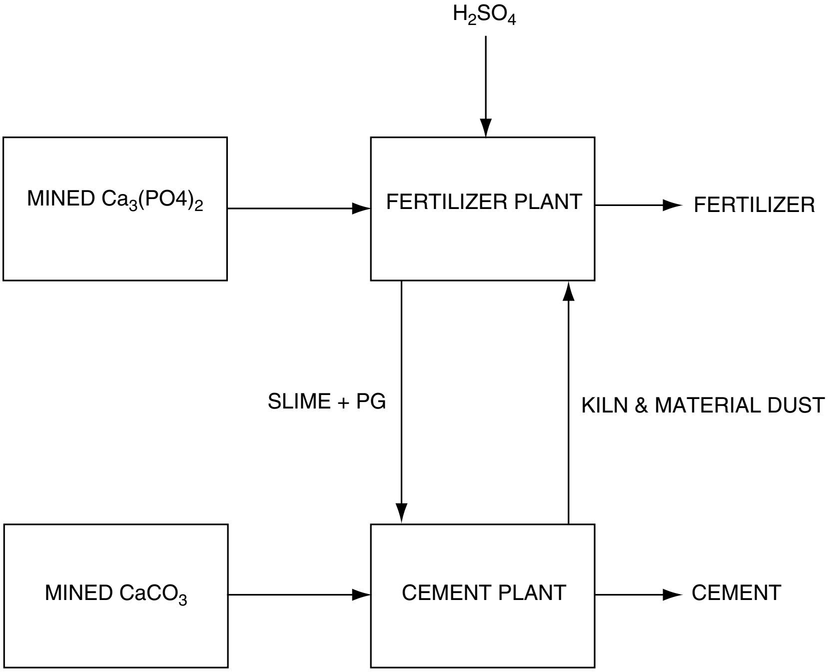


FIGURE 16.5. Mass flow diagram of a fertilizer-cement complex.

Fc Is the Classic Production Cost

In 1995, the average U.S. fertilizer plant manufactured 831,607 tons of phosphate fertilizer. In addition, the average annual production cost in a fertilizer plant was \$169.66 million. Therefore, the 1995 fertilizer production cost, Fc, was \$169,660,000/831,607 or \$204.02/ton.

Fwt Is the Direct Cost of Waste Treatment

In this example, this cost includes that spent in preventing phosphogypsum piles from reaching the environment; in storing and preventing the escape of tailing wastes; in abating air contaminants from the production of fertilizer from sulfuric acid reactors; and other types of waste treatment. Some real examples of plant expenditures for these waste treatments include the following:

IMC-AGRICO spent \$1 million in 1994 for water testing and new wells as a neighborly gesture but denies that its mining caused water pollution and subsidence problems (Satchell 1995). The company has voluntarily spent \$6.8 million to plug a sinkhole and control the spread of contaminants to the groundwater. Assuming the life of a stack to be 10 years, this cost becomes \$0.83/ton of fertilizer (Fwt2).

CORGILL fertilizer placed at least 18 in. of compacted clay over a layer of at least 15 ft of natural clay at its Hillsborough County, Florida, mine (Newborn 1992). The company spent \$22 million for lining the base of the new stack, plus another \$5 million to close the existing gypsum stack. These expenditures for top coverings, when projected to 1995 costs, resulted in \$3.73/ton of fertilizer (Fwt3).

IMC completed lining a new stack at its New Wales mine in Polk County, Florida, with 20 million ft^2 of plastic for a cost of \$70 million. This expenditure for bottom lining amounted to \$9.67/ton (Fwt4).

Therefore, Fwt = Fwt1 + Fwt2 + Fwt3 + Fwt4 = \$15.46/ton.

Fnd Is the Indirect Cost of Environmental Damage to Nearby Owners

In 1987, the State of Connecticut established values of fish killed by acid leakage; this situation amounted to \$1,082 (Anonymous 1988) (Fnd1) or \$0.01/ton of fertilizer.

On December 21, 1994, IMC-AGRICO agreed to pay \$1.1 million to settle a lawsuit filed by the Environmental Protection Agency (EPA), which had charged the company with violating water pollution limits at nine locations due to slime waste–contaminating groundwater. The cost of the legal proceedings came to \$1.35/ton of fertilizer (Fnd2).

In 1994, the phosphate industry contributed \$100,000 to some 25 "green ground societies." In 1988, the Audubon Society received \$42,500 from IMC alone. These indirect costs amounted to \$0.19/ton of fertilizer in 1995 dollars (Fnd3).

The industry also contributed to candidates for state and local offices. Total contributions were $160,000 for 1994. Donation indirect costs for election campaigns amounted to $0.20/ton of fertilizer (Fnd4).

Therefore, Fnd = Fnd1 + Fnd2 + Fnd3 + Fnd4 = $1.75/ton.

Fxd Is the Intangible Cost of Environmental Damage

These costs have been elusive to pin down and may very well be the greatest of the three types of damage costs. In the research effort described in this chapter, we established the following specific values.

Florida phosphate mining companies have paid about $1 billion in taxes to the state in the past 25 years. This amounts to a mean yearly value of $51/ton/yr, assuming that 50% of them are small and operate on a small margin of profit, thereby being adversely affected by state action to enforce pollution-control measures.

Assuming, again, that 50% of these plants are then estimated to have closed because of waste-treatment pressure, the public lost 25% of the $51 million of revenue taxes due to these plant closures. Hence, Fxd1 = $15.33/ton of fertilizer.

Land value in the Tampa, Florida, industrial area decreased from about $1,250/acre to $600/acre mainly because of fertilizer pollution over a period of 10 years, or $65/acre/yr (G. M. Lloyd, personal communication 1995).

Therefore, $65 times 1,000 acres times 17 industries times 5 gypsum stacks/industry divided by 831,607 tons/yr equals $6.64/ton of fertilizer equals Fxd2.

In 1996, the State of Florida purchased 38,251 acres of land along five riverbanks for a price of $21,270,000, or $547.77/acre (Browning 1996). This purchase was aimed at purifying these lands from the wastes mainly from fertilizer plants over a 10-year period. Therefore, Fxd3 = $2.56/ton of fertilizer. The total intangible costs we were able to identify were calculated to be

Fxd = Fxd1 + Fxd2 + Fxd3 = $15.33 + $6.64 + $2.56 = $24.53/ton of fertilizer.

Substituting our computed values in Equation (1), we obtained a real production cost of

$204.02 + $15.46 + $1.75 + $24.53 = $245.76,

when the major measurable environmental damages were considered.
Using the same procedure to compare cement plants, the cost relationship becomes

Creal = Cc + Cwt + Cnd + Cfd.

Cc Is the Conventional Cost of Cement Production

An average of 984,000 tons of cement was produced per cement plant in the United States in 1995 at an average production cost of $49.2 million.

Therefore, Cc = $49,200,000/984,000 tons = $50/ton of cement.

Cwt Is the Cement Waste Treatment Direct Cost

Cement kiln dust is a major waste to the air environment and needs collection and disposal to protect the surrounding air. Kessler (1995) reports that typically each percent of dust wasted increases the specific heat consumption by about 0.7% and decreases clinker production by 0.5%. He gives the dust losses costs as Cwt1 = \$4.08/ton of cement, because of the loss of raw material; Cwt2 = \$4.59/ton by feed crushing, conveying, drying, and grinding costs; Cwt3 = \$1.02/ton for transporting, conveying, handling, and de-dusting; and Cwt4 = \$3.06/ton for landfill maintenance, monitoring, pile maintenance, and closing.

Total waste-treatment costs for kiln dust becomes

$$\begin{aligned}\mathrm{Cwt} = \mathrm{Cwt1} + \mathrm{Cwt2} + \mathrm{Cwt3} + \mathrm{Cwt4} &= \$4.08 + \$4.59 + \$1.02 + \$3.06\\ &= \$12.75/\text{ton of cement.}\end{aligned}$$

CNN Is the Indirect Cost of Cement Plant Waste Environmental Damages

In 1992, the EPA fined Lafarge's Michigan and Alabama cement plants \$1.8 million for violating air emission operating rules (Ferguson 1993). The cost (Cnd1) was \$1.94/ton of cement.

Lafarge's switch to power-plant fly-ash from ground shale may have saved as much as \$600,000 in fines levied by the U.S. District Court (Anonymous 1994). The additional cost (Cnd2) resulting from environmental violations was \$0.62/ton of cement.

In 1992, a local customer sued Lafarge for \$1 million over improper disposal for chromium-tainted materials over a 5-year period. The cost of legal compensation (Cnd3) for affected victims was \$0.22/ton of cement.

These three indirect costs amounted to

$$\mathrm{CNN} = \mathrm{Cnd1} + \mathrm{Cnd2} + \mathrm{Cnd3} = \$1.94 + \$0.62 + \$0.22 = \$2.78/\text{ton of cement.}$$

Cad Is the Intangible Cost of Cement Plant Environmental Damages

Since 1990, Hillary Clinton has been a director of Lafarge Cement Corporation, one of the largest operators of cement kilns fueled by burning hazardous wastes (Zweig 1992). In 1991 the former president's wife earned \$30,000 from Lafarge. It may have been inferred by some that this may indirectly influence state and federal policies on Lafarge. The cost of potential influence (Cad) in this case was \$0.03/ton of cement.

All cement damage costs equal

$$\mathrm{Cwt.}\ \mathrm{Cnd} + \mathrm{Cxd} = \$12.75 + \$2.78 + \$0.03 = \$5.56/\text{ton of cement.}$$

The real cement plant production costs equal

$$\mathrm{Creal} = \mathrm{Cc} + \mathrm{Cwt} + \mathrm{Cnd} + \mathrm{Cxd} = \$50 + \$12.75 + \$2.78 + \$.03 = \$65.56/\text{ton.}$$

EBIC of a Phosphate Fertilizer and Cement Plant

When these two plants are located in the same complex, all direct costs of waste treatment, indirect costs of environmental damages to nearby neighbors, and intangible costs to the general public are eliminated. In addition, transportation costs of replaced fertilizer raw material and cost of replaced fertilizer raw material decrease the real production costs.

The transportation cost of the replaced raw material (Fr) was computed to be \$20/ton of fertilizer, and the cost of the replaced fertilizer (Fr) raw material was computed to be \$0.07/ton of fertilizer. Likewise, corresponding values for the cement plant were

Car = \$6.00/ton of cement

and

Cram = \$10/ton of cement.

Calculations were made for the production of 1 ton (total) of EBIC product, as shown schematically in Figure 16.5. Because 3.5 tons of cement can be produced for each ton of fertilizer product, each ton of EBIC product would consist of 0.22 tons of fertilizer and 0.78 tons of cement.

To illustrate the truth of the economic value of transportation of wastes away from an industrial site, take the case of the American Waste Transport Corporation. This company is one of the major contract transporters of solid waste in southern California and southwest Arizona. In fiscal 1999, it had revenues in excess of \$12 million according to a company statement (Clark 2000). It supplies materials to processors that convert waste into fertilizer and compost or burn it to produce energy. In our complex system, we would eliminate this massive transportation cost and perform the same or similar reuses within the complex. To continue, the CEO of U Biomes said that they currently transport 1,400 tons per day of “green wastes” and that “green waste recycling is expected to grow dramatically as California begins to comply with its state recycling law, which requires diversion of 50% of waste from landfills.” This rush to transporting and reusing solid wastes is also occurring in many other states to comply with similar laws. The proposed system (EBIC) eliminates these unnecessary and burdensome transportation costs.

Conclusions[1]

It is seen that the real societal cost of products is more than the classic cost. In the case of fertilizer, it is 20% greater, and in the case of cement, it is 34% greater. By industrial

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[1] The author acknowledges the financial assistance received from the National Science Foundation, in the form of partial funding for this project. Thanks, too, to G. Michael LLoyd of the Florida Institute of Phosphate Research and to Victor Turiel of Pennsuco Cement Corporation for assistance in obtaining significant data.

complexing, so that waste products of one industry become raw materials for the other, environmental damage costs can be eliminated and the raw material and transportation costs can be reduced. These result in a cleaner environment and lower product cost. In the case of fertilizer and cement plants—in a weighted sense—there is a 20% saving as compared with real societal cost and 37% saving as compared with real cost. The author wants these industries to become aware of the advantages of industrial complexing, both financially and environmentally, so that whenever feasible such two or more industry complexes can be achieved to the benefit of the manufacturer, the consumer, and the environment in which we live.

Tables 16.2 through 16.7 summarize the data previously described in this chapter. The real production costs of a ton of fertilizer and a ton of cement are $245.76 and $67.09, respectively, and are shown in Table 16.2.

Environmental damage accounts for 20% of the fertilizer production cost and 34% of the cement production cost (shown in Table 16.3). When credits for replacing some raw material and eliminating some transportation are taken into account, the classic fertilizer and cement production costs are $183.95 and $34.00/ton, respectively

TABLE 16.2
Real Production Costs[a] of Fertilizer and Cement Plants

Type of Cost	*Cost per Ton of Fertilizer*	*Cost per Ton of Cement*
Classical production cost	$204.02	$50.00
Direct environmental damage	$15.46	$14.28
Indirect environmental damage	$1.75	$2.78
Intangible environmental damage	$24.53	$0.03
Real production cost (Total production cost)	$245.76	$67.09

[a] All costs are projected to 1995 dollar values.

TABLE 16.3
Comparison of Classical Production Costs[a] of Free-Standing Fertilizer and Cement Plants with Real Production Costs[a] per Ton of Product

Industry	*Classical Cost*	*Real Cost Including Damage Costs to Society*	*Cost of Environmental Damage*	*% Cost of Environmental Damage*
Fertilizer	$204.02	$245.76	$41.74	20
Cement	$50.00	$67.09	$17.09	34

[a] All costs are projected to 1995 dollar values.

(shown in Table 16.4). These result in savings of 10% and 32%, respectively (shown in Table 16.5). The total savings to fertilizer and cement plants are $61.81 and $33.09/ton, respectively, when using the EBIC (Table 16.6). Table 16.7 presents a comparison of production costs of a ton of EBIC products and the corresponding classic and real costs for equivalent masses of products for free-standing plants. It can be seen that—in a

TABLE 16.4
EBIC Costs in a Fertilizer[a]-Cement Industrial Complex

Type of Cost	*Cost per Ton of Fertilizer*	*Cost per Ton of Cement*
Classical production cost	$204.02	$50.00
Credit for replaced raw material	–$0.07	–$10.00
Credit for transportation of replaced raw material	–$20.00	–$6.00
EBIC cost	$183.95	$34.00

[a] All costs are projected to 1995 dollar values.

TABLE 16.5
Comparison of Classical Production Costs[a] of Free-Standing Fertilizer and Cement Plants with EBIC Costs[a] per Ton of Product

Industry	*Classical Cost*	*EBIC Cost*	*Savings Due to EBIC*	*% Savings Due to EBIC*
Fertilizer	$204.02	$183.95	$20.07	10
Cement	$50.00	$34.00	$16.00	32

[a] All costs are projected to 1995 dollar values.

TABLE 16.6
Comparison of Real Production Costs[a] of Free-Standing Fertilizer and Cement Plants with EBIC Costs[a] per Ton of Product

Industry	*Real Cost Including Damage Costs to Society*	*EBIC Cost*	*Savings Due to EBIC*	*% Savings Due to EBIC*
Fertilizer	$245.76	$183.95	$61.81	25
Cement	$67.09	$34.00	$33.09	49

[a] All costs are projected to 1995 dollar values.

TABLE 16.7

Comparison of Production Cost[a] of a Ton of EBIC Product (0.22 Ton Fertilizer + 0.78 Ton of Cement) and Equivalent Masses of Free-Standing Plant Products[a]

Industry	*Classical Cost*	*Real Cost*	*EBIC Cost*	*Saving Over Classical Cost*	*% Saving Over Classical Cost*	*Saving Over Real Cost*	*% Saving Over Real Cost*
Fertilizer (per 0.22 ton)	\$44.88	\$54.07	\$40.47	\$4.41	10	\$13.60	25
Cement (per 0.78 ton)	\$39.00	\$52.33	\$26.52	\$12.48	32	\$25.81	49
Total (per ton of EBIC product)	\$83.88	\$106.40	\$66.99	\$16.89	20	\$39.41	37

[a] All costs are projected to 1995 dollar values.

weighted sense—1 ton of EBIC product would be \$16.89 cheaper than the classical cost and \$39.41 less expensive than the real cost, which translates into 20% and 37% savings, respectively.

Marketing Unused Waste Resources

There may be instances in which the EBIC will not be able to reuse all the waste materials completely. These cases could occur despite the concerted efforts of the industrial plants to reuse all wastes as raw materials. In these rare situations, the EBIC participants should market these wastes in an efficient economical manner.

I recommend marketing these excess wastes using a system that I have been advocating officially since 1969 (Nemerow 1985). I maintained that the assimilative capacity of the environmental resource should play a major role in determining the price industry should pay for polluting it. The more assimilative capacity available, the lower the unit sale price of the wastes. As the assimilative capacity of the resource (air, water, or land) becomes limited, the higher the unit cost to discharge the waste. Instead of discharge or treatment, of course, I recommend that another external buyer purchase these excess units of waste at the price predetermined by its detrimental effect on the environment. In that way, the EBIC participants will not be forced to pay for polluting and the external environment will remain clean. If a buyer cannot be found, then the EBIC members have a choice either to pay a fair value for their untreated discharge into the environment or to pay for its treatment before discharge.

Lomborg's reviewer (Bailey 2001) points out that "clearly regulation has worked to improve these common areas (air and streams): our air and streams are cleaner than they were. But there is good evidence that assigning property rights and market mechanisms to such resources would have resulted in a faster and cheaper cleanup."

Further discussion of using this marketing system was also presented in another book (Nemerow and Agardy 1998b). As an example, you may determine that the beneficial damage of the industry's biochemical oxygen demand (BOD) pollutant was $10/lb, in which case, the industry would have the option to buy a certain number of BOD pounds "rights" to discharge at that price or treat its waste to remove that number of pounds. As described in the previous references in 1985 and 1998, as the available limit of BOD diminishes, the market price of a unit of BOD increases. The reason for this is to protect the water-quality level of the receiving water. Industry is discouraged from using the last available BOD units to preserve that water-quality level. Because the cost of buying BOD rights increases as the available resources decrease, industry must treat its waste, usually at a lower unit cost than buying rights. Of course, the possibility of buying lower cost BOD unit rights from another industry exists in the free market system.

The free market system could also be used for buying land unit rights for solid wastes and air-capacity rights for air pollutants. This system of buying and selling "pollution rights" should be based on the benefit lost of the resource by adding an incremental pollutant load. The environmental benefit lost becomes greater—and, hence, so does the pollutant right cost—as the available environmental resource gets used up. This method of pricing, though more difficult to compute unit costs, is preferable to an arbitrary price placed on the right by some overseeing agency. It is even preferable, in my opinion, than a truly free market pricing system because it is based on more tangible and measurable environmental damage costs.

Although Rinda E. Vas (2000), editor of *Environmental Technology,* found that "there are several kinds of market-like mechanisms that might be employed in environmental regulation," she does not quite include a *market charge based on damage costs* as one of them. In evaluating current emission trading systems, Bryner (1999) gets closer to my proposal of a system by concluding that "emission trading programs should lead to other, more powerful regulatory innovations that *will more effectively encourage ecologically sustainable activities* [the emphasis is mine]. Emission trading programs should be designed as a transition to a *system of emission fees or taxes and other efforts to reflect true costs in prices and to create more powerful incentives to reduce and prevent pollution* [again the emphasis is mine]." He goes on to conclude that "the ultimate test of an emission trading program is its contribution to a more fundamental shift in practices aimed at reducing pollution, improving efficiency, and conserving resources." All of these practices are incumbent in my market pricing system proposed in 1985 and 1998, and again in this book. Solomon and Lee (2000) write that "despite the success of these trading systems in affordably reducing emissions, they have been criticized by several environmental organizations for allegedly creating toxic hot spots (local areas with excessively high emissions or concentrations of a hazardous air pollutant."

The utility business is similar—in certain instances—to the environmental resource business. Units of power can be sold at a price based on real market value. The real market value can be reached by adding the existing kilowatt-hours charge to a unit local societal monetary loss to arrive at total real value.

Available power supplies are decreasing fast—especially during peak power demand periods—in San Diego, California, as an example (Rose 2000). Rose (2000) writes that "some suggest that power companies are holding back (construction of power plants), perhaps waiting for a crisis that would provide them with the financial incentive to build." Rose also quotes Edwin Guiles (president of San Diego Gas & Electric), "We are in favor of all solutions being considered—new generation, demand-side alternatives, distributed generation—but we have to make sure there is a solution that can deliver in the time period we have."

I suggest that the purchase of kilowatt-hours be based on benefit costs of not having power units above the basic level that exists. Such benefit losses include the following:

1. Lower standard of living from lack of adequate air conditioning and heating
2. Loss of industry production increase due to unavailability of power
3. Lack of municipal growth due to inadequate power, and so on

One can then put added values on each excess of these and sell kilowatt-hours to all consumers. The added dollar kilowatt-hour charge can be used by power companies as an incentive to build and produce more kilowatt-hour capacity. When extra kilowatt-hour capacity is met, the dollar extra kilowatt-hour charge can be dropped until demand exceeds supply again.

As recently as July 2001, the op-ed editor of *The Wall Street Journal* questioned whether pricing emissions is possible and advocated its use. The editor wrote that "thus, by providing flexibility and financial incentives, a cap-and-trade program [his term for selling resources] will result in more abatement from those firms who can do it at relatively lower cost. The net will be the same amount of over-all pollution reduction, but achieved at lower cost than would be obtained under traditional regulation."

The editor referred to the Energy Information Administration as stating that the cost of power plant CO_2 reductions according to the requirements of the Kyoto Treaty agreement could be as much as 4% of the gross domestic product (GDP). However, "in a scenario offered back in 1998 by the Clinton administration's Council of Economic Advisors, if the U.S. buys permits for its excess emissions—so that it doesn't have to reduce by very much its own emissions—the cost would be only 0.1% of GDP." With these facts in mind, the editor recommends that the Bush administration propose a domestic cap-and-trade program for CO_2 that could, of course, be expanded to Canada and Mexico and later to Latin America and then the world.

Alternative Energy Sources to Reduce Resource Depletion, Costs, and Environmental Impacts

Alternative Energy Solutions

Because energy is so vital and integral to any industrial complex, it is appropriate to discuss ways and means of reducing its cost to a minimum before using some form of it in an industrial complex. We must consider all forms of reasonable alternative energy sources not only to minimize their production costs, but also to reduce depletion of natural resources and to eliminate any potential adverse effects on the environment.

Introduction

Since the current use of fossil fuels (coal and oil) and nuclear fuels is too costly, arises from nonrenewable fuel resources, or results in too great an adverse environmental impact, the search goes on for renewable, nonpolluting, and economical alternative energy sources. In this section, I present potential alternative solutions to the use of fossil and nuclear fuels and the adverse environmental effects that they create. You are urged to attempt to use any of these suggested alternatives in applications that are suitable to your particular situations.

Alternative Energy Sources

The following six fuel sources are suggested as alternatives to fossil and nuclear fuels for producing electricity with little or no adverse environmental impacts:

1. Hydrogen fuels
2. Wind energy
3. Solar energy
4. Geothermal energy
5. Wave energy
6. Other electrical energy sources

Each of the aforementioned sources of energy should be considered in solving environmental problems when it is desired to conserve and diminish the polluting effects of other nonrenewable fuels.

Hydrogen Fuels

Although hydrogen fuels are sufficiently important and currently in use to warrant a complete chapter, they are mentioned briefly here to make certain that their potential for use is considered to the fullest. Hydrogen is produced today primarily from the electrolysis of water into its separate constituents of hydrogen and oxygen. In this case, some conventional electric fossil fuel power is required, but theoretically, hydrogen can also be produced in a number of other ways. It can also be produced biologically from anaerobic decomposition of various agricultural wastes (see "Other Electrical Energy Sources" later in this section).

The production of hydrogen by electrical disassociation of water is shown in Figure 16.6. The most recent use of hydrogen fuel as an alternative to fossil (gasoline) is in automobiles. The hybrid cars—partly fueled by hydrogen—have been quite successful. Automobiles completely powered by hydrogen are also forecasted for the near future—within the next few years. One maker is even proposing a hydrogen-fueled auto with the hydrogen fuel tank installed in the rear seat area of the automobile to avoid the fuel delivery and loading problem. This would represent a highly desirable alternative solution to the combustion-gas air pollution problem caused by gasoline-fueled autos.

Wind-Generated Power

By the year 2004, more than 13,000 megawatts of wind power had been installed worldwide. California alone had 1,600 megawatts of wind power in use to provide enough electricity for over 750,000 homes. Wind farms—a collection of individual windmills at one location—have been increasing to a point where the U.S. Department of Energy predicts that wind power costs will drop to $0.2 cents/kW-hour from the current value of $0.3–0.6 cents.

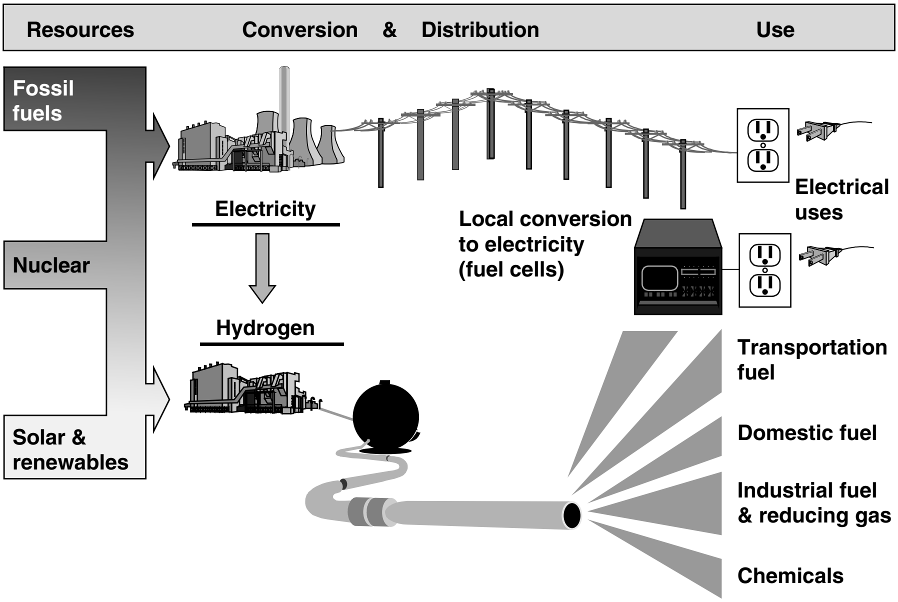

FIGURE 16.6. Production of hydrogen by electric disassociation of water. Used with permission from John Wiley and Sons.

Wind Production

Wind farms use large blades to catch the wind and turn rotors to produce electricity. A modern wind farm may contain as many as 500 wind turbines connected to a transmission grid. They produce electricity much the same as steam engines use steam to turn rotors of generators to produce electricity, except that in this case wind instead of steam does the work.

A wind speed production of at least 12 miles/hr is usually required to produce electricity. When the wind is not blowing at this speed, no electricity is produced, and the main transmission line is not being supplemented with wind-generated electricity. However, as soon as the wind speed picks up sufficiently, the wind electricity begins again to supplement that in the main transmission line. This creates no problems, because wind energy usually represents a small percentage (2–4%) of the total power being transmitted.

Environmental Impacts of Wind Power

Wind plants create no air pollution, do not use or waste any water, or despoil the land, but they may produce effects on vision, audio, and wildlife.

Vision

Because wind farms contain so many turbines that which are mounted on top of tall towers (some 350 ft high), they often are visible at a great distance from the farm. Some people object to the sight of large wind farms just as some people object to crowded buildings in a city. However, as these farms become more prevalent and as people get used to seeing them, they may become more acceptable to most people in the area. In fact, some people may even claim that their appearance is desirable from an artistic standpoint. Modern planners and architects face the challenge of designing these farms so that they are desirable for the surrounding humans.

Audio

Other people may be concerned about the noise created by the wind farms. That noise may be mechanical or aerodynamic in nature.

Mechanical noise is produced by parts rubbing against or hitting other parts, and has virtually disappeared in the newer designed rotors. The aerodynamic noise, which is that swishing sound emitted as the blades pass the tower, can be masked by proper use of sound-barrier construction. Once again, some people even claim that the swishing sound is rather soothing, similar to that generated by ocean waves hitting the shores.

Wildlife Effects

Bird populations can be threatened by the wind farms. The ground below the mills is disturbed during construction, which in turn attracts mice, prairie dogs, and burrowing animals. These in turn attract raptors such as hawks and eagles that prey on them. These birds may perch on top of the wind generators for reasons of hunting for prey and often get caught in the spinning blades. Lately, farms are designed to contain tubular towers to prevent birds from perching on them. In addition, they turn more slowly than those of earlier design. When compared to other industries such as mining and coal combustion, the environmental effects on birds are much less.

The use of wind farms is greatly enhanced by the realization of farmers of the value of their land. They have found that by leasing the land for the wind farms, they can overcome increasing costs of fuel for cultivating crops on the land.

Solar Energy Power

The science of converting the sun's energy into electricity is often referred to as *photovoltaic (PV) science*. Although the concept was known since Edmond Becquerel discovered it in 1839, it wasn't until 1954 when the first photovoltaic cell was created in the Bell Labs. These cells are semiconductor devices that convert light directly into electricity. They are generally made of silicon with traces of other elements. Although PV cells are quite sophisticated in design, they are very simple to use. The PV cells are mainly low-voltage DC devices with no moving or wearing parts. Once they are installed, no maintenance outside of an occasional cleaning is required. However, most of these systems do include a battery (storage) and need some water just like automobile batteries.

PV Cells

PV cells (solar) consist of layers of semiconductor materials with various electronic properties. The bulk of the cell is usually silicon based, along with a minor amount of boron to lend a positive electrical charge to it. A thin layer on the front of the cell is painted with phosphorous to render the other part of the cell negatively. The union between the two cell layers will then contain an electric field at the junction. When the photons of daylight hit the solar cell, some of these photons are absorbed at the junction, which then frees the electrons of the silicon material. If and when the photons possess enough energy, the electrons will be able to move through the silicon and into an external circuit. They give up their energy as they flow through the external circuit and result in producing electricity to power all kinds of small and often larger electronic devices before returning to the solar cell. The entire process is solid state with no moving parts and no materials released or consumed in the process. Despite what many people believe, these solar cells work better in colder weather than in hot, mainly because they produce electricity from light rather than heat. As long as sunlight is reduced no more that 20% of full sun, sufficient photons will be released to operate under these partly cloudy conditions.

Benefits of Solar-Powered Electricity

Some of the many benefits of using solar energy to replace fossil- or nuclear-fueled sources include:

1. The fixed costs of operation remain constant for the life of the system.
2. The solar system is independent from any other source of fuel.
3. Several solar cells can be joined to increase the output capacity of the system.
4. No noise occurs from operating the system.

5. No so-called *greenhouse gases* are entitled, as is the case with fossil fuels.
6. The solar-power system possesses a long operating life.
7. Cost of operation and maintenance is competitive with other energy types.
8. Because of its nonpolluting nature, solar cells are widely known as "clean and green."

Some Environmentally Related Uses of Solar Cells

Because so many people in developing countries have little or no access to electricity, these solar cells are predicted to compete more favorably with conventional sources of power. Some of the uses that you might not normally consider for solar-derived electricity are the following, which also are environmentally enhancing:

1. Powering weather stations to provide dependable economical electricity
2. Powering pumps to transmit water from remote reservoirs and lakes or from rivers that are not readily accessible
3. Telecommunication of river water stages and even magnetic detection of earthquakes causing tsunami effects in oceans
4. Electricity to remote homes such as vacation or seldom-used buildings
5. Nuclear power radiation detection systems
6. Portable light and electric systems
7. Remote lagoon aeration systems for waste treatment
8. Disaster and all types of civil defense warning systems
9. Corrosion systems for pipes (cathodic protection)
10. Remote charging of batteries in hybrid and other autos
11. Powering difficult-to-access air pollution sampling and analysis stations

The reader is urged to think of his or her own uses of solar-generated electricity that may also benefit the environment and serve as an alternative to fossil-fueled electricity.

Geothermal Energy

Geothermal energy is obtained from heated water, steam, or soil that is derived from deep within certain land masses. There are two main uses for this energy: (1) hot water is used to create electricity or to provide hot water heating or warming, and (2) the thermal mass of the soil or groundwater is used to drive heat pumps that provide either heat or cooling. The first use is more widely known and used and is obtained from geothermal geysers that find their way to the earth's crust.

The aforementioned uses are not really from renewable resources; however, with properly calculated use, they can almost approach the "renewable" classification. The heated water, steam, or soil will gradually be depleted if overdrawn from the ground. This valuable ground resource will slowly regenerate itself over time so that if the withdrawal at the surface is timed to match the regeneration rate, the resource will be considered renewable. In any event, it will not deplete itself as fast as fossil or oil fuels are depleted by normal mining techniques. In addition, heat reservoirs are considered immense in magnitude compared to current or even projected use, thus rendering geothermal energy practically renewable.

In the United States, the production of electricity from the geothermal energy of the earth's interior heat is centered in northern California. These geothermal sources provided slightly more than 7% of California's electricity in the 15-year period ending the twentieth century. Geyser production has decreased from supplying about 2,000 megawatts in 1989 to 1,100 megawatts near the turn of the century. Unfortunately, because of the specific location of these geothermal fields, most individual households cannot use this energy. However, direct use of the heated water can save establishments as much as 80% in their fuel bills.

Geothermal Ground Source Heat Pumps for Residential Use

Heat pumps can reduce both air-conditioning peak loads and winter-heating loads. In addition, they are typically used to heat water (or as hot water) in households and buildings.

Economics of Geothermal Energy

Geothermal electricity can be produced practically and economically for about $0.5 cents/kW-hour, slightly higher than wind or solar energy. This higher cost is largely because it is necessary to drill deeper today to produce a given amount of power than in earlier years. It has been suggested (and even used) that the economics of geothermal power can be improved through co-production of other goods from high-temperature brine extracted from the depths of the ground. While geothermal power applications require more advances in exploration and drilling, heat pump direct uses require that the engineer and the consumer understand the technology. It may be more expensive to install geothermal energy systems at the start, but over the long term the benefits may make it economically and environmentally worthwhile.

Effects on the Environment

Air pollution relative to conventional fossil-fuel energy production will be minimized when selecting geothermal energy instead. It produces only about one-sixth of the CO_2 and none of the NOxs or sulfur gases that fossil-fuel plants emit. For these reasons alone, this method of energy production can be a very environmentally friendly alternative to fossil-fuel energy.

Amount of This Energy Already Being Produced

In 1998, geothermal energy provided 0.4% of the electricity generated in the United States. This amounted to 14.3 billion kW of electricity to more than 1,400,000 homes. At that time, it was growing at a rate of slightly less than 3% over an 8-year period. Worldwide, geothermal energy totaled slightly more than 8 million kW or about 3% of the 3,180 kW used worldwide.

Some Examples of Geothermal Energy Uses

The Oregon Institute of Technology has been heated by the direct geothermal energy since 1964. In Iceland, geothermal energy is used to provide the majority of households with heat. Tax neutrality, continued and increased federal funding, continued and expanded production tax credits, resource identification, renewable portfolio standards, contractor education, and the issuing of air emission standards have been and are being used to encourage continued use of geothermal energy.

The reader is urged to consult the U.S. Department of Energy's web site for more information of geothermal energy. In addition, the Renewable Energy Policy Project maintains a rather detailed bibliography of the uses of this form of energy. It is located at 1612 K Street N.W., Suite 202, Washington, D.C.

Ocean Wave Energy

How Wave Electric Energy Is Created

The entire earth's surface including the ocean is heated by the sun. This creates wind that pushes against the surface of the ocean and forms waves. Waves can travel hundreds and thousands of miles from the beginning of their propagation. They are being continuously supplemented by new winds. These waves keep their energy long after the winds that created them have abated. These same waves represent one of the most concentrated and consistent sources of renewable energy. When compared to conventional fossil-fuel generation, wave energy provides the increased advantage of a limitless free supply of energy, along with a total lack of environmentally polluting emissions. However, even today there appears to be no agreement among professionals as to the most efficient technological approach to the use of wave energy.

Types of Wave-Energy Conversion Systems

The kinetic energy of waves may be converted into electrical energy mainly by four different systems:

1. *Tapered channel systems* that funnel incoming waves into shoreline reservoirs that raise the water above sea level. The head of water then is directed down through a turbine, which then drives a generator producing electric energy.
2. *Float systems* consist of buoys that sit on the ocean's surface. As the ocean rises and falls, the relative motion between the float and the ocean floor drives hydraulic pumps or pistons. This kinetic energy is also used to drive a turbine and a generator producing electricity.
3. *Oscillating water column systems* are fixed in place and are devices in which waves enter the column and force air up past a turbine. As the wave retreats, the air pressure drops, resulting in the turning of a turbine that once again drives a generator and produces electric energy. The first of this type of system was produced in Japan to power a light on a buoy used for navigation.
4. *Underwater turbines* collect and contain the movement of the ocean's currents and use this energy to drive slow-moving blades.

These, in turn, drive a generator directly—similar to an above-ground windmill—to produce electricity.

Advances

Many of today's professionals and equipment manufacturers think that the time has arrived for the era of wave energy usage to accelerate. Technological advances have progressed sufficiently to make this form of energy cost effective when compared to fossil-fueled power. These advances include those of marine engineering that have come from the offshore drilling industry, which provide ocean-tested "off-the-shelf" components at reasonable prices. In addition, the cost of electronic control devices that optimize the efficiency of the technology has been reduced.

Environmental Considerations

Wave-generated electrical energy is a source of clean renewable energy and does not produce any objectionable greenhouse gases. When selecting this method to produce electrical energy, one must also be aware of certain disadvantages that may hamper their acceptance. First, the sea is unpredictable at best and devastating at worst (such as when the tsunami hit in the South Pacific). Under these conditions, the facilities must be designed to be able to withstand pressures many times the normal wave pressures. Second, these wave-generating systems may cause alterations to shore lines and local ecosystems. And thirdly, the electricity produced will vary because of the variability of the waves.

Generally, the average wave power level should be more than 15 kW/m to generate wave energy at competitive prices.

Other Electric Generated Systems

Agricultural residues, farm animal wastes, human sewage sludges, and other biomasses can be fermented to produce combustible gases such as methane. The gas can be burned directly in a boiler to convert water to steam, which then can drive a turbine connected to a generator to produce electrical energy.

When an ample supply of these biomasses is available, it is desirable to consider them as an alternative energy source. Not only does one produce a valuable energy resource at a competitive cost, but one also rids the environment of a source of waste causing adverse environmental effects. In these systems, bacteria do the work required in digesting the organic matter of these wastes to free CH_4 (methane). Bacteria require no compensation for this work, but they do require proper design and operation of equipment.

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