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Benefit-Cost of Energy Conservation

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There are compelling technical and economic arguments for adopting a balanced approach to the energy problem, one that gives equal consideration to increased supply and to effective end-use of energy (1-11). Historically, there has been a tendency to focus upon energy sources, with less attention given to improving the efficiency of processes and devices which utilize energy for performing various tasks. To the extent that it has been introduced to the recent energy debate, conservation has too often been equated with curtailment (e.g., lowered thermostats, reduced speed limits, etc.) rather than improved end-use efficiency.

A supply-dominated approach was economically sound in an era of abundant and inexpensive energy resources. Today, however, we can no longer look forward to steadily expanding supplies of energy at ever-declining real cost. In fact, we have seen in recent years a sharp reversal of the long-term decline (in real terms) of energy prices. The outlook is for even higher cost in the future, particularly for those energy forms where regulatory actions have thus far restrained prices below the level of replacement cost.

Technologically and financially, there are ample opportunities for saving energy in all sectors of the economy. As shown in Figure 1, the second law efficiency of energy usage in the United States is estimated to be about 8%. Even the industrial sector, our largest user of energy, operates at an overall efficiency of only about 13%. Several studies have disclosed the potential economic advantages of energy conservation for various industrial processes. These studies (1) indicate that approximately 25%--the equivalent of 4.5 million barrels of oil per day--of projected 1985 energy usage in manufacturing could be saved through conservation measures whose capital and total costs would be equal to or less than those needed to obtain comparable amounts of new energy supply.

The primary sources of energy inefficiency in manufacturing are burning of high-grade fuel to produce low-temperature process heat, loss of high-grade waste heat to the environment, and use of

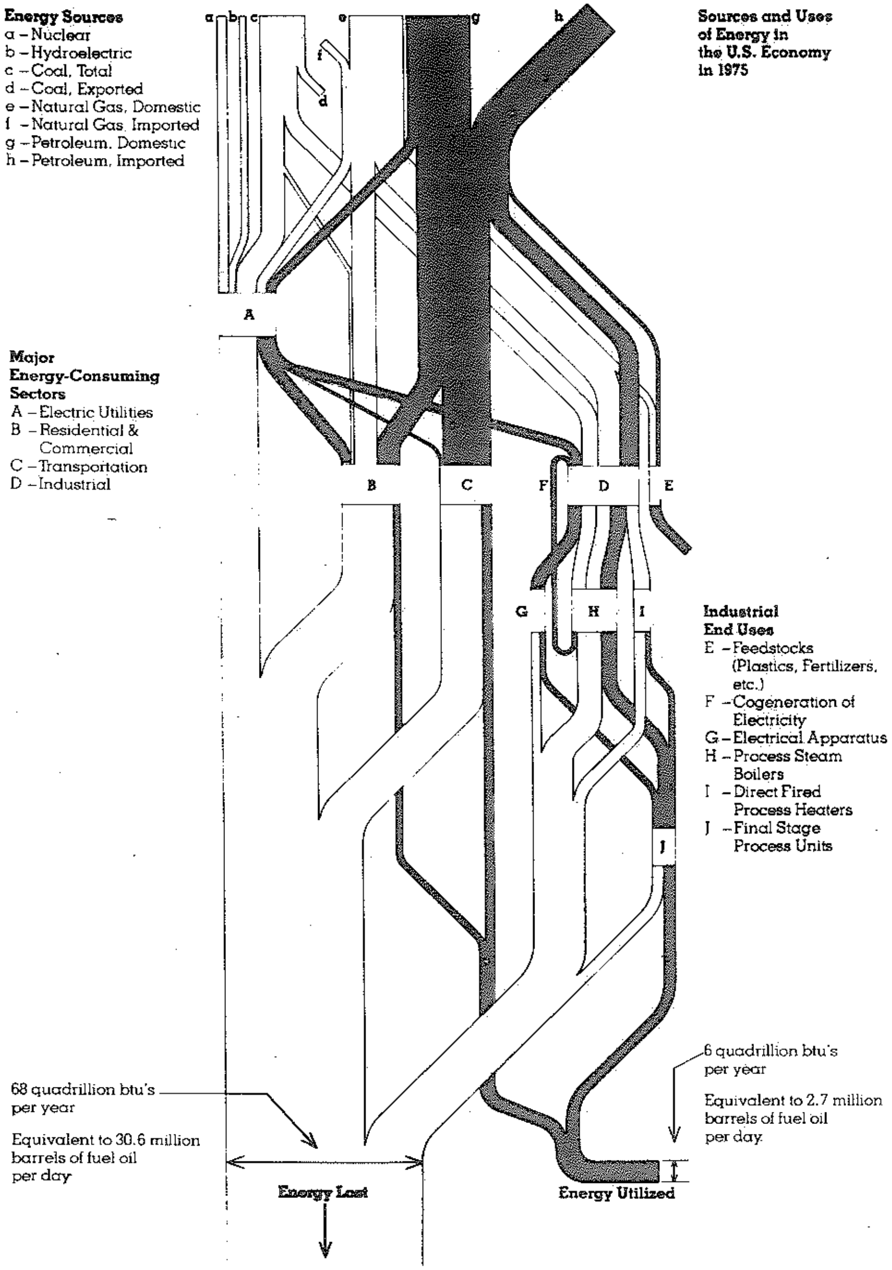

Figure 1. Effectiveness of energy usage in the U.S. economy (based upon availability)

certain manufacturing processes having inherently large thermodynamic loss mechanisms. Inefficiencies of specific processes can be attacked only through systematic analysis of the operations particular to each industry—a task that requires intimate and detailed knowledge of the technologies involved. However, the first two sources of inefficiency are common to all manufacturers and can be reduced with technology applicable to many industries. These inefficiencies, which are found in fuel-fired kilns, furnaces, boilers, ovens, and dryers, can be reduced through various process rearrangements, including recycling of waste energy and recovery of waste energy.

Rising Replacement Costs for New Energy Supplies

The advantages of implementing a vigorous energy efficiency program in industry can best be seen by comparing the capital cost of new energy supply facilities to the cost of energy-saving equipment. Because of the diminishing store of readily recoverable fossil fuel resources, development of new energy supplies consumes an ever-increasing amount of capital for each unit of energy production capacity (3).

Apart from the Middle East, where reserves are still easily accessible, most new petroleum or natural gas production facilities (e.g., U.S. outer continental shelf, North Sea, Alaska) require anywhere from $5 billion to upwards of $10 billion for each Quad per year of equivalent fuel energy provided (1 Quad per year = 10^{15} Btu/year = 456,000 bbl per day = 33,400 Megawatts thermal). Synthetic gas and oil obtained from coal will be even more costly, probably in excess of $15 billion per annual Quad.

New coal supplies are still obtainable at a capital cost of $1.5 billion to $2.0 billion per Quad per year. However, the mining, processing, and combustion of coal is attended by serious environmental and safety problems that may ultimately limit its rate of consumption, or at least cause increases in the cost of supply. Moreover, coal does not possess the flexibility of application inherent to oil and gas. The industrial sector could undoubtedly substitute more coal for such purposes as the raising of process steam, but any major increase in our reliance upon coal will depend, for the most part, upon its greater use by electric utilities.

The capital cost is, of course, the highest when the energy is provided in the form of electricity. For every Quad per year of delivered electricity, the capital investment in facilities for fuel supply, generation, transmission, and distribution will range from $50–60 billion for coal-based systems, to over $70 billion for nuclear generation.

The sharp rise in capital cost of new energy supplies has created a large disparity between the price of energy and the cost of its replacement. From 1950 to 1970, energy prices and replacement costs declined annually in real terms at a rate of 1.7%.

Electric utilities were building larger and more efficient plants, and energy suppliers were using more sophisticated methods of discovering, producing, and distributing natural gas and oil. In those days, all forms of replacement energy, even regulated natural gas, had costs equal to or less than the price of supplied energy.

Just before the oil embargo, however, replacement costs started to climb sharply. From 1971 to mid-1973, prices rose to their real 1950 level. For the first time in our history, the replacement cost of energy sources jumped above the average price paid by consumers. The postembargo oil price increases have accelerated this trend; as Table I shows, the replacement cost for the mix of energy consumed by industry in mid-1977 exceeded the price of supplied energy by about 37%. The cost disparity in September 1977 was the most for natural gas (59%)--it would be even higher if Alaskan gas, liquified natural gas, or synthetic fuels were used as replacement fuels--and the least (0%) for coal.

Table I.
Average Price and Replacement Cost of Energy Used in Industry

Energy form	Percent of industrial use	Dollars per million Btu of delivered energy (September 1977)	
		Average spot price	Replacement cost
Coal	19.0	$1.05	$ 1.05
Petroleum	34.0	2.41	2.88
Natural Gas	34.5	2.08	3.30
Electricity	12.5	9.00	12.90
Weighted Average		$2.86	$ 3.93

For electricity, a utility's rate structure represents an average of the cost of new plant and equipment plus older, less expensive facilities. For example, a utility might charge an industrial customer at a rate of 2.6 cents per kilowatt hour (kWh), based upon an after-tax return on assets of about 8%. If this electricity were to be produced exclusively from new plant facilities, the rate would have to rise to 4.1 cents per kWh in order to realize the same return on assets. Of course, the allowable return for utilities is now usually higher than 8% (with higher prime rates, rate-setting bodies may permit returns of up to 12%). Thus, marginal costs for electricity will rise still further.

These disparities between price and replacement cost of energy cannot last, because new energy will eventually supply a large fraction of the demand, causing replacement costs to reach a new plateau. The costs of synthetic fuels, and perhaps of electricity from either solar or breeder reactor sources, will be at least 1.5 to 2 times the current replacement costs.

Industrial Conservation - The Effective Use of Capital

In contrast to new energy supplies, capital equipment costs have remained almost constant in real terms. The economic potential of energy conservation using such equipment can be seen by considering typical energy-saving measures available in certain industrial processes (Table II). Capital costs for energy saving are substantially lower than those for equivalent new energy supply facilities.

As previously noted, such cost-effective efficiency improvements represent an energy saving of 25% for all manufacturing (about 10 Quads per year at 1985 projected usage). An estimated $125 billion in capital investment would be needed to realize these savings. This is a large investment but smaller than that required to provide a comparable amount of energy from new supply facilities. In fact, the capital investment needed to produce the same 10 Quads per year of coal, petroleum, gas, and electricity from new sources would be at least $170 billion.

Individual industries will vary substantially from the average 25% figure for savings because of wide differences in the relative efficiency of current practices compared to the most advanced technology available in each particular industry. Also, various industries have a different mix of energy-saving opportunities with regard to fuel types (i.e., the fraction of savings that can be achieved in coal, oil, gas, and electricity).

The lower capital cost figures for various conservation measures (relative to the investment needed for new energy supplies) provide only a rough indication that such measures will yield attractive economic returns to the investor. Detailed payback calculations, similar to those discussed later for waste heat recovery equipment, are needed to establish economic feasibility in each specific case.

Most manufacturers have identified methods of saving energy that require little or no capital investment. These methods, often simply of a housekeeping nature, have largely been implemented in response to higher prices and shortages occurring in the post-embargo era. True efficiency gains, however, require capital investment, often of such a high level as to strain the resources available to a particular industry. Nevertheless, it is desirable to stimulate these conservation investments, at least up to the point where the cost of additional conservation equals the marginal cost of energy from new fuel and electricity facilities, for otherwise our capital resources will be misallocated and the competitive edge of our industry will be eroded.

In addition to limited capital, at the present time there are other barriers that impede the flow of investment capital into industrial energy conservation.

Table II. Examples of the Cost Effectiveness of Energy Conservation Measures

Conservation Measure	Energy Saved and Type of Fuel	Capital Cost of Unit (1975)	Specific Capital Cost of Conservation Measure ($/Annual Quad)	Capital Cost of Comparable New Supply
RECUPERATORS ON STEEL REHEAT FURNACES	10^8 Btu/hr for 170 Tons/hr Steel Throughput	$480,000	$0.7 x 10^9 per Quad of fuel	10 Times Conservation
BOTTOMING CYCLES ON STEEL REHEAT FURNACES	5.0 MW electricity for 170 Tons/hr Steel Throughput	$3.4 x 10^6	$28.4 x 10^9 per Quad of electricity	2 Times Conservation
COGENERATION OF ELECTRICITY AND PROCESS STEAM IN STEEL PLANTS	40 MW electricity for 10,000 Ton per day plant	$41.4 x 10^6	$34.6 x 10^9 per Quad of electricity	1-3/4 Times Conservation
DRY QUENCHING OF COKE IN STEEL INDUSTRY	4 x 10^9 Btu/day of steam fuel plus 1.4 x 10^6 Btu/day coke (3000 Ton/day plant)	$9.3 x 10^6 (retrofit) $5.3 x 10^6 (new plant)	$4.7 x 10^9 per Quad of fuel $2.7 x 10^9 per Quad of fuel	Same as Conservation 1½ Times Conservation
REDUCED CURRENT DENSITY IN HALL PROCESS ALUMINUM REDUCTION CELLS	2160 kWh per Ton of Primary Aluminum	$350 per Annual Ton of Primary Aluminum	$48 x 10^9 per Quad of electricity	1-1/4 Times Conservation
BOTTOMING CYCLES ON CEMENT KILNS	4.7 MW electricity for 600 Ton/day plant	$2.7 x 10^6	$23.9 x 10^9 per Quad of electricity	2½ Times Conservation
AIR PREHEATERS ON ETHYLENE PLANT PROCESS HEATERS	4.8 x 10^{11} Btu/yr for 1400 Ton/day plant	$1.14 x 10^6	$2.3 x 10^9 per Quad of fuel	3 Times Conservation
STEAM GENERATION FROM AMMONIA PROCESS HEATER FLUE GAS	11 x 10^6 Btu/hr for 1000 Ton/day ammonia plant	$130,000	$1.1 x 10^9 per Quad of fuel	2 to 6 Times Conservation
FEEDWATER PREHEATERS ON STYRENE PLANT PROCESS HEATER	4 x 10^6 Btu/hr for 400 Ton/day styrene plant	$17,000	$0.6 x 10^9 per Quad of fuel	4 to 12 Times Conservation
OPTIMIZATION OF CRUDE DISTILLATION PREHEAT TRAIN	23 x 10^6 Btu/hr 100,000 bbl/day refinery	$1.0 x 10^6	$4.7 x 10^9 per Quad of fuel	1½ Times Conservation
POWER RECOVERY TURBINES ON HIGH PRESSURE REFINERY PROCESS FLOW STREAMS	11.0 MW electricity for 100,000 bbl/day refinery	$2.8 x 10^6	$8.2 x 10^9 per Quad of electricity	8 Times Conservation
INCREASED USE OF BARK AND WOOD WASTES AS FUEL IN PAPER INDUSTRY	10^9 Btu/day for 400 Ton/day mill	$1.7 x 10^6	$4.8 x 10^9 per Quad of fuel	1½ Times Conservation

- The average price of energy charged to manufacturers has not yet caught up with the rapidly increasing replacement cost of new energy supply.
- Energy users require a higher rate of return on their investment than do regulated energy producers (e.g., gas and electric utilities) who face lower risks.
- Most manufacturers demand a higher rate of return on so-called "discretionary" investments (e.g., conservation) relative to main-stream investments (e.g., expansion of capacity), because investments critical to maintaining market share must be given high priority.
- Federal, state, and local regulations restrict the generation of byproduct electricity by many manufacturers.

These factors play an important part in the decision making process of any manufacturer considering energy conservation investment. In fact, most manufacturers will not invest in conservation measures having a payback period in excess of about 2 years. An illustration of how these factors can distort an investment decision can be seen from an actual case study.

In November 1976, the manager of a plant located in a Southern state presented to his corporate management a proposal to install a 4700-kW electricity generator powered solely by waste heat. The turnkey price of this "bottoming cycle" generator was $2.7 million. Upon review by management, the proposal was rejected; the plant continues to purchase electricity from a utility. This electricity is generated by consuming the equivalent of about 188 barrels of petroleum a day. Had the company elected to purchase the waste heat recovery unit, the electricity produced would have replaced not only an equal amount of new fuel supply facilities, but also a corresponding amount of new generating capacity earmarked by the utility in its expansion plans. The items that would have been replaced cost either $5 million or $8 million for coal- or nuclear-based systems, respectively--two to three times the cost of the energy-saving proposal.

Top management of the company assessed the plant manager's proposal on the basis of 2.6 cents per kWh paid for purchased electricity. This analysis resulted in a projected after-tax return on investment (ROI) of 22%, considerably less than the 30% expected from the discretionary investments that do not increase production. Although the company's typical ROI criterion was only about 15% and its average return on assets only 10%, top management rejected the proposal.

If, however, the company had been paying for electricity the 4.1-cent replacement cost appropriate to new electricity supply, the generator would have earned a return well above 30% and management would have undoubtedly approved the project.

Payback Periods of Selected Conservation Measures

Capital spending analysis consists of evaluating the investment outlay in terms of the economic gain that it will provide.

The investment outlay is represented by the net investment required for the new equipment or change in operation, and the economic gain is represented by estimated operating cash flows generated by the investment. Different companies use different criteria for comparing outlays and gains.

A widely used method of analysis is that based upon the internal rate of return. Also known as the Discounted Cash Flow method, this approach is based on the criterion that the sum of the present value of all cash flow returns associated with a given project be equal to the initial investment outlay; namely,

$$C_o = \sum_{n=1}^{N} \frac{NCF_n}{(1 + i)^n}$$

where

C_o = initial investment outlay
NCF_n = net cash flow at year n
i = internal rate of return
n = year, 1, 2.....N
N = economic life in years

The factor $1/(1 + i)^n$ transforms each expenditure or net cash flow to its value at time zero. The net cash flow at year n is defined as the savings resulting from the investment, i.e., savings resulting from a reduction in purchased fuel or electricity, minus the costs chargeable to operation and maintenance (O&M), federal taxes, and loan payments.

$$NCF_n = S_n - OM_n - FT_n - ALP_n$$

where

S_n = savings on fuel for year n
OM_n = operation and maintenance costs for year n
FT_n = federal taxes for year n
ALP_n = annual loan payments for year n

The required rate of return varies with the company, industry, and general economic climate. An average required rate of return, based upon the weighted averages of debt and equity, value line risk factors, bond ratings, and riskless borrowing rates, can be obtained for an industry for all its investments. The industry-wide average of the after-tax rates of return calculated from these parameters for the chemical, petroleum, and paper and pulp industries, and for utilities is 15%, 16%, 15%, and 13%, respectively.

Another method of analysis consists of evaluating the gross payback period, namely the ratio of the initial investment outlay C_o for a project to the yearly pre-tax gross savings GS_1 at the time of investment ($GS_1 = S_1 - OM_1$). The gross payback period is related to the internal rate of return. Obviously, changes in tax regulations, depreciation, accounting, financing procedures, escalation in savings and costs, etc. will change directly the internal rate of return and indirectly the gross payback period.

Figure 2 shows the relationship between internal rate of return and gross payback for a specific set of tax regulations (10% investment tax credit, 50% tax rate), 6% per year increase in power, fuel, and O&M costs, and sum-of-digits depreciation for both 10-year life (for recuperators and heat exchangers) and 20-year life (for power generation equipment and boilers). We see that life has little effect on the internal rate of return for gross payback periods less than about 3 years.

Recent studies by Thermo Electron Corporation have shown that certain forms of waste heat utilization (e.g., recuperators or process steam boilers) provide a better return on investment than that obtainable from bottoming cycle generators. The optimum choice of heat recovery strategy depends, in part, upon the temperature of exhaust heat available.

As shown in Table III, the waste heat from just 3 major industries (chemicals, petroleum refining, and paper) represents over 5 Quads per year of total energy--equivalent to about 1/6 of all energy consumed by the entire industrial sector. The largest potential for high-temperature (600°-1000°F) heat recovery is in petroleum refining. The chemical industry has a large amount of waste heat at intermediate (300°-600°F) temperatures, and all three industries have large amounts in the low-temperature (<300°F) range. Because over 70% of the waste heat is at temperatures below 300°F (with over 50% under 150°F), there is generally less opportunity for economical heat recovery in the paper and pulp industry than in either the chemical or petroleum refining industries.

Table III.
Summary of Available Waste Heat in the Chemical, Petroleum Refining, and Paper and Pulp Industries

Industry	Temperature Ranges				Total Amount 10^{15} Btu/yr
	<150°F	150-300°F	300-600°F	600-1000°F	
	Percent of Total				
Chemical	7	44	44	5	2.3
Petroleum Refining	15	29	29	27	1.2
Paper and Pulp	52	20	28	0	1.6

Current trends in heat recovery include retrofitting existing process furnaces and installing new furnaces with combustion air

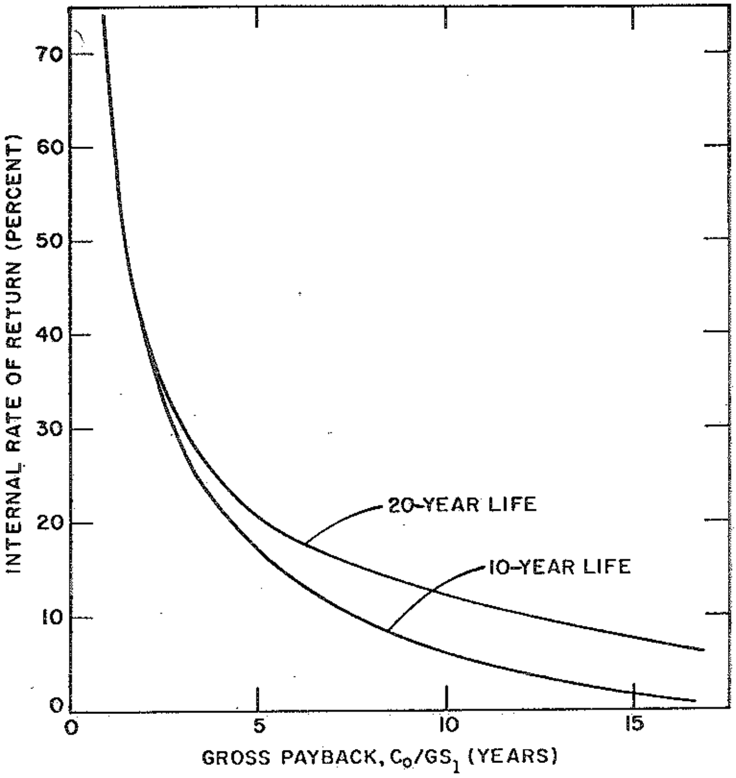

Figure 2. Internal rate of return vs. gross payback. Gross payback is defined as the ratio of capital expenditures to pretax gross savings at the time of investment (C_0/GS_1)*: 50% tax rate; 10% investment tax credit; S.O.D. depreciation; 6% per year increase in power, fuel, and operation and maintenance costs.*

Table IV.
Comparison of Paybacks for Different
Recovery Measures

ENERGY RECOVERY METHOD	Payback (Years)	
	500°F Flue Gases	800°F Flue Gases
Electrical Generation by Bottoming Cycle		
20×10^6 Btu/hr waste heat	~8.0	4.7
40×10^6 Btu/hr waste heat	5.5	3.5
80×10^6 Btu/hr waste heat	3.8	3.6
Combustion Air Preheating		
$20\text{-}80 \times 10^6$ Btu/hr waste heat	~1.0	~1.0
Steam Generation (125 psig)		
20×10^6 Btu/hr waste heat	1.8	0.8
40×10^6 Btu/hr waste heat	1.5	0.7
80×10^6 Btu/hr waste heat	1.2	0.4
Power Recovery from Product Stream by Means of Hydraulic Turbine	1.0	2.0

Based on: 7000 hours of operation per year, fuel at $2.00/$10^6$ Btu, electricity at $0.03/kWh.

preheating (especially in the petroleum industry where 600°-1000°F waste heat is available), generating process steam with waste heat boilers, adding product stream heat exchangers, and providing power recovery turbines in pressurized power streams.

Comparative gross payback periods for the various energy recovery approaches are shown in Table IV. For high-temperature flue gases (800°-1000°F), process steam generation appears to be more economical than combustion air preheating or electrical generation by bottoming cycles. At a 500°F flue gas temperature, the reduced steam production (caused by the boiler pinch-point problem) makes combustion air preheating more economical than steam generation. At both flue gas temperatures, the economic paybacks between the two waste heat recovery technologies are only marginally different. On the other hand, electrical generation by bottoming of waste flue gases (with steam or organic working fluid Rankine cycles) is generally not competitive with either combustion air preheat or steam generation. For flue gas temperatures above 800°F, sufficiently high-pressure steam can be generated to make the economics of back-pressure turbines (steam expanded to 125 psig for use in process) for electrical production approach those for combustion air preheating. In practice, the choice between combustion air preheat, steam generation, or electric generation is dictated not only by economics, but also by the specific plant requirements for steam or electricity and by the availability of natural gas and/or oil. For a process with few steam requirements, electrical generation may be the optimum selection.

As energy prices continue to rise towards their replacement cost levels, industry will undoubtedly respond by increasing investment in energy-saving process equipment. Those manufacturers who move quickly to take advantage of available conservation opportunities can expect to gain a significant competitive advantage over their less efficient rivals.

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