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PRIORITY LISTING OF INDUSTRIAL PROCESSES BY
TOTAL ENERGY CONSUMPTION AND POTENTIAL FOR SAVINGS

Final Report

A. J. Streb

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Division of Industrial Energy Conservation
MASTER

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Priority Listing of Industrial Processes
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Total Energy Consumption
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Potential for Savings

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I. Introduction

Over the past several years, extensive efforts have been applied to the collection of detailed data relating to the consumption of energy in major U. S. industrial sectors. These data were assembled by various research organizations to help plan the development of new energy sources and to provide targets for energy conservation activities. The composite volume of data which presents energy consumption profiles for major industrial sectors and for the most energy intensive processes within each sector is monumental. As a result, the task faced by users of the data who need an overview of industry to develop energy conservation program priorities is a difficult one.

Ideally, every process unit in industry should function near optimum efficiency and fully utilize all waste energy generated within the process itself. Every major process unit must, therefore, be critically examined to determine the magnitude and location of energy losses occurring therein and to identify potential process modification or alternatives which will enhance overall energy utilization efficiency. Priorities can then be established to provide a proper relationship between the application of energy conservation effort and the potential benefit of such effort.

Under a purchase order initiated by the Industrial Energy Conservation Division of the Energy Research and Development Administration, the contractor has surveyed eight of the most energy intensive segments of U. S. industry to quantify the energy consumed in the principle^a process units, to identify areas in which significant improvement appear possible and to rank the process units in terms of total energy consumption and the potential for improvement.

A flow diagram showing the principle elements of the contract effort is presented in Figure I-1. Initial concentration was placed on a review of the data base developed by other investigators and on the selection of a suitable "figure of merit" by which all processes could be compared. The eight industrial sectors

were then selected and studied to identify the key process units in each, the energy consumption figure of merit and Process Alternatives for Conservation of Energy. Processes and process alternatives were then ranked in terms of total energy consumption and the potential for improvement.

This report summarizes the results of the contract effort.

PROJECT FLOW DIAGRAM

Figure I-1

II. Process Unit Performance Assessment

To determine the principle targets for energy conservation programs, the major energy intensive industrial process units must be examined relative to the total consumption and the efficiency of utilization.

The first law of thermodynamics gives us some insight into process efficiency, in that we can sometimes compare the total energy leaving a process as useful product to the total energy entering the process. Energy which escapes the useful streams leaving the process altogether is thereby quantified.

A more meaningful measure of process efficiency is derived from the second law of thermodynamics. A second law efficiency parameter compares the amount of work available from a given quantity of energy to the amount of work needed to run the process. The concept of available work is illustrated by several simple examples in Table II-1. A performance assessment based on availability, simultaneously accounts for both the quantity and quality of energy passing through the system. Properly executed, this kind of performance assessment can tell us how much work is lost in a given process, how much of the lost work is wasted, and where it is wasted.

Table II-1 - Available work provided by sources and need by end users. (Ref. 7)

Note: $T_1(\text{hot}) > T_2(\text{warm}) > T_3(\text{ambient}) > T_3(\text{cool})$

S O U R C E S	Work W_{in}	Fuel with heat of Combustion H	Heat Q_1 from hot reservoir at T_1
	(e.g., water power, wind power, raised weight) or elec- tricity if the wall socket is treated as the source	(e.g., coal, oil, gas)	(e.g., geothermal source, solar collector source) also fission reactors and fos- sil-fuel plants if alternatives to thermal opera- tion are excluded
	$B = W_{in}$	$B = \Delta H *$ (usually to within 10%)	$B = Q_1 \left(1 - \frac{T_0}{T_1} \right)$
E N D U S E S	Work W_{out}	Heat Q_2 added to warm reservoir at T_2	Heat Q_3 extracted from from cool reservoir at T_3
	(e.g., turning shafts, pumping fluids, propelling vehicles)	(e.g., space heating, cooking, baking, drying)	(e.g., refrigerating, air conditioning)
	$B_{min} = W_{out}$	$B_{min} = Q_2 \left(\frac{1 - T_0}{T_2} \right)$	$B_{min} = Q_3 \left(\frac{T_0}{T_3} - 1 \right)$

* An exact consideration is required for each fuel

"Effectiveness" is the term generally used to describe a second law performance parameter. Various definitions of effectiveness are used. In general, they are all some ratio of useful work to work input. A comparison of effectiveness of two different processes designed to perform the same task is meaningful. A comparison of effectiveness of different processes which perform different tasks is usually not meaningful because the magnitude of the parameter can be distorted by feedstock or process products which have high intrinsic energy content (e.g. paper, petroleum products, etc.)

An absolute measure of the performance of a given process is given by the concept of "Lost Work". Lost Work is the difference between the available work flowing into a process and the available work flowing from the process. The total annual Lost Work for a given process is an absolute measure of the national annual energy consumption burden contributed by that process, and therefore represents a good basis for the establishment of energy conservation priorities.

An industry summary table was prepared for each of the principle energy intensive industries. The tables are presented in Section III. These tables present within a unified format the major process units, and characterizes each of these process units by various parameters and figures of merit. The information contained in each of the heading and columns of the industry summary tables is described and defined as follows:

Industry - identification of basic industrial sector, (e.g. steel, paper, glass, etc.)

Total Production - total end product produced annually in traditional units of measure (e.g. tons) for a given base year.

Energy Consumption - total primary energy of all types which goes into annual production.

Base Year - reference calendar year on which production and consumption statistics were gathered.

Process Description - briefly defines the process unit as it is currently constituted.

- TP - Throughput is the total national annual end product production which experiences a given process.
- E_T - Total Energy⁺ of all types entering given process including fuels work and feedstock. Energy will be considered to be "prime" energy i.e. energy at the prime source. In the case of electrical power utilization by a given process, prime energy is the fuel to the power plant. Where "waste" energy is used, prime energy is the energy leaving the process from which it is wasted.
- E_{use} - Useful Energy⁺ delivered from system. With respect to the first law of thermodynamics the total energy leaving the system equals the total energy entering. Useful energy however only includes the useable outputs whether or not they are actually used.
- B_{in} - Available Work Input⁺ resulting from total energy (E_T) entering system. This term considers not just the quantity of energy but also its quality at the prime source as defined above. With respect to the second law of thermodynamics, it is the maximum amount of work which can be extracted from all input streams - fuel, heat, work and feedstock. Because of the very high work potential of feedstock and product stream within the petroleum process streams, only the consumables were considered. In all other cases, all potential work was carried through the analysis.
- B_{min} - Minimum Work⁺ required to run the process in given configuration. This term is based on a judgement of practical limitations on system losses and component efficiencies. This term is not the theoretical thermodynamic minimum.
- B_{use} - Useful Available Work⁺ delivered from system is the total work available from the useful energy (E_{use}) delivered from the system.
- B_{ut} - Utilized Available Work⁺ is that part of the useful available work which is actually employed.
- L - Lost Work⁺ is the total loss of availability occurring as a result of the process i.e. $B_{in} - B_{ut}$
- η - Efficiency First Law is the ratio of useful output to total input energy without regard to quality i.e. E_{use}/E_T
- ϵ - Efficiency Second Law is the ratio of useful available output to minimum work required to run process i.e. B_{use}/B_{min}
- U_1 - Input Utility Factor is the ratio of the minimum work input B_{min} to the actual work input B_{in} i.e. B_{min}/B_{in}
- U_2 - Output Utility Factor is the fraction of the useful available work leaving the system which is actually utilized i.e. B_{ut}/B_{use}

PACE - Process Alternative to Conserve Energy is any alternative to a given process which results in energy saving.

PS - Potential Saving is the potential saving of available work either within the process (increase in E) or external to the process (increase in U).

A scale is presented in Figure II-1 as an aid to aid to better envision the relationship of the various energy and availability states. The significance of some of the defined parameters contained within the industry summary table also become somewhat more obvious when Figure II-1 is studied.

The relative magnitudes of the availability and energy terms shown in Figure II-1 is correct relative to themselves, i.e. $B_{in} > B_{min} > B_{use} > B_{ut}$ and $E_T > E_{use}$, but not necessarily correct relative to each other i.e. B_{min} is not necessarily larger than E_{use} .

+ - Note all energy and availability terms are normalized to unit throughput (TP).

Figure II-1 Scale of approximate relationship between typical System Energy and Availability States

III. Survey of Energy Intensive Industries

The survey was limited to the eight most energy intensive industries.

They are:

- 1) Steel
- 2) Petroleum Refining
- 3) Paper
- 4) Olefins and Derivative Products
- 5) Aluminum
- 6) Textiles
- 7) Cement
- 8) Glass

The effort consisted of a review of specific studies previously performed for each industry, determination of total national production and energy consumption in each sector on a consistent basis, the selection of the principle process units, the development of the process performance parameters discussed in Chapter II and presentation of the results in tabular form (Tables III-1 through III-8).

The majority of the data contained in the summary table was taken directly or derived from the industry survey sources listed in the references. Some data not found in the available reference sources was obtained through personal contact with representative of industry or simply estimated.

Where more than one reference source was available for a given parameter, considerable variance was sometimes found. An effort was made to resolve such variance through personal contact with the authors of the source material. When this was not possible, a judgement was made.

The energy consumption data presented is intended to show conditions as they currently exist. In many cases, better equipment or more advanced processes are already standard practice in new or replacement plants.

The following sections treat each of the eight industrial sectors. Comments are presented relative to the data sources, assumptions, results and most obvious areas for potential energy savings.

A. Steel

The energy consumption profile for the steel industry is presented in Table III-1. All input data was derived from references (1) and (3). Data were adjusted to a 1973 reference year. It was assumed that 38% of the steel production results from the processing of scrap and the balance from virgin materials.

The principle energy conservation target areas in the steel industry which have been noted are:

- 1) Preheating of raw materials with waste heat or the preservation of thermal energy in feeds between preparation and charging.
- 2) Dry quenching of coke and recovery of sensible heat content.
- 3) Collection and utilization of B.O.F. off-gas.
- 4) Cogeneration of electricity and steam.
- 5) Improved effectiveness of blast furnace blast air preheater.

TOTAL PRODUCTION 151×10^6 TONSTOTAL ENERGY CONSUMED 3.8×10^{15} BTU

PROCESS DESCRIPTION	TP 10 ⁶ TONS YEAR	ET 10 ⁶ BTU TON	E USE 10 ⁶ BTU TON	B IN 10 ⁶ BTU TON	B MIN 10 ⁶ BTU TON	B USE 10 ⁶ BTU TON	B UT 10 ⁶ BTU TON	η	U_1	ϵ	U_2	L(TP) 10 ¹² BTU YR	PACE
ORE PREPARATION	94	1.42	.05	1.38	1.38	.02	0	.04	1	.015	0	130	CHARGE BLAST FURNACE WITH HOT SINTER P.S. = 1.9×10^{12} BTU
COKE PRODUCTION	94	25.9	24.4	25.6	25.3	23.9	20.9	.94	.99	.94	.87	442	
AIR PREHEATING FOR BLAST FURNACE	94	1.92	1.47	1.97	1.97	.76	.76	.77	1	.39	1	114	IMPROVE HEATER EFFEC- TIVENESS TO 75% P.S. = 67×10^{12} BTU
IRON PRODUCTION IN BLAST FURNACE	94	20.6	13.8	20.7	20.7	14.2	14.2	.67	1	.69	1	611	INCREASE AIR BLAST TEMPERATURE WILL DE- CREASE COKE REQ'D (SEE AIR PREHEATING)
OPEN HEARTH STEEL PRODUCTION	39.8	12.58	8.41	11.96	11.76	7.45	7.45	.67	.98	.63	1	179	
BASIC OXYGEN STEEL PRODUCTION	83.3	9.1	8.0	8.6	8.6	7.44	7.14	.88	1	.86	.94	122	COLLECT BOF OFF - GAS P.S. = 25×10^{12} BTU
ELECTRIC FURNACE STEEL	27	9.2	7.7	9.1	9.1	7.2	7.2	.84	1	.79	1	51	
REHEATING FOR ROLLING	151	7.90	6.75	7.51	7.51	6.37	6.37	.85	1	.85	1	172	
WORK CONTENT OF PRODUCT												1072	
TOTAL WORK ACCOUNTED												2893	

B. Petroleum Refining

The energy consumption profile for the petroleum refining industry is presented in Table III-2. Total consumption and production is based on a 1973 reference year. The input data was derived from data extracted from references (2) and (4).

The selected process units are those which are expected to consume the bulk of the refinery energy based on a forward projection of refinery product demand. The relative throughputs for each process were determined from reference (4) for each of three national regions. A weighted average of these relative throughputs based on total production in each geographic region was determined and used for the purpose of this study.

An energy and availability balance was developed for each of the process units based on energy inputs tabulated in reference 4. The availability of fuels, steam and electricity was assumed to equal their respective energys as they entered the process. Minimum availabilities were estimated based on limited knowledge of required process temperatures. It was assumed that process heaters could be built to operate at a temperature 250°F above the temperature of the process effluent and that all steam could be delivered at 500°F 500 PSI. The energy and availability of the feedstock and product were omitted because their magnitude was very large in comparison to resources actually consumed thereby tending to disguise the system energy losses.

Although the unit processes which were considered differ greatly from each other, certain common elements are found in most. Notably, the process heaters which are employed are similar, if not identical, from process to process. It is within the process heater that the largest single loss of availability occurs due to heating streams to moderate temperature with virgin energy capable of doing much more work. Great losses of availability also result from large uses of steam which is evidently generated specifically to meet process requirements.

It is recommended that these areas be examined much more carefully.

Because of the similarity in process components, particularly these components which can be credited with large availability losses, the petroleum refining processes should not only be considered individually but also as a block.

The principle energy conservation target areas which have been noted for the petroleum industry are:

- 1) Improved overall effectiveness of process heaters. Use high temperature topping cycle to extract "front end" availability. Add exhaust heat recovery apparatus.
- 2) Improved steam generation equipment, consider generation of more steam with exhaust from process heaters.

INDUSTRY PETROLEUM REFINING

BASE YEAR 1973

TABLE III-2

TOTAL PRODUCTION 4.537×10^9 bbl/yr

TOTAL ENERGY CONSUMED 2.96×10^{15} BTU/YR
PLUS 23×10^{15} BTU/YR NET FEEDSTOCK

PROCESS DESCRIPTION	TP 10^9 bbl YR	E _T * 10^6 BTU bbl	E USE 10^6 BTU bbl	B IN* 10^6 BTU bbl	B MIN* 10^6 BTU bbl	B USE* 10^6 BTU bbl	B UT* 10^6 BTU bbl	η	U ₁	ϵ	U ₂	L(TP) 10^{12} BTU YR	PACE
ATMOSPHERIC DISTILLATION	4.72	.184	-	.184	.112	.007	0	-	.61	.06	0	869	ADD TOPPING CYCLES TO PROCESS HEATERS AND STEAM GENERATORS COMBINED SAVING P.S. = 427×10^{12} BTU
VACUUM DISTILLATION	1.77	.095	-	.095	.054	.003	0	-	.57	.06	0	168	
CATALYTIC CRACKING	1.54	.181	-	.181	.126	.008	0	-	.70	.06	0	278	
ALKYLATION	.36	.702	-	.702	.463	.034	0	-	.66	.07	0	252	
ISOMERIZATION	.18	.241	-	.241	.168	.010	0	-	.70	.06	0	43	ADD HEAT RECOVERY SYSTEMS TO HEATER EXHAUST COMBINED SAVING P.S. = 32×10^{12} BTU
CATALYTIC REFORMING	.91	.358	-	.358	.221	.017	0	-	.62	.08	0	325	
HYDROCRACKING	.32	.301	-	.301	.229	.009	0	-	.76	.04	0	96	
COKING	.45	.237	-	.237	.152	.010	0	-	.64	.07	0	107	
NAPHTHA DESULFURIZATION	1.14	.083	-	.083	.055	.004	0	-	.66	.07	0	95	
TOTAL WORK ACCOUNTED												2233	

C. Paper Industry

The energy consumption profile for the paper industry is presented in Table III-3. The majority of the input data was derived from references 1 and 3. All data was adjusted to a 1972 reference year. The entire annual production was assumed to consist of a product mix containing 8% newsprint, 33% writing paper, 42% corrugated container board, 17% folding boxboard. The relative throughputs for the selected major process units was adjusted to this product mix.

A number of interesting observations were made during the preparation of the energy consumption profile. The total lost work associated with the kraft pulping process was found to be surprisingly large. It was also noted that the total steam and electrical power requirements of the combined plant processes closely matched the steam and electrical power production potential of a cogeneration system operated with kraft process wastes. Another area of great waste was found in the non-use of a large fraction of bark and hogged wood which results during feedstock preparation.

The principle energy conservation target areas for the paper industry are:

- 1) Cogeneration of steam and electrical powers from kraft process waste streams.
- 2) Burn bark and hogged wood resulting from feedstock preparation.
- 3) Incorporate heat recovery on kraft process lime kiln.

INDUSTRY PAPER

BASE YEAR 1972

TABLE III-3

TOTAL PRODUCTION 64 x 10⁶ TONS

TOTAL ENERGY CONSUMED 1.5 x 10¹⁵ OIL GAS ETC.
2.5 x 10¹⁵ FEEDSTOCK

PROCESS DESCRIPTION	TP 10 ⁶ TONS YR	ET 10 ⁶ BTU TON	EUSE 10 ⁶ BTU TON	BIN 10 ⁶ BTU TON	B MIN 10 ⁶ BTU TON	BUSE 10 ⁶ BTU TON	BUT 10 ⁶ BTU TON	η	U ₁	E	U ₂	L(TP) 10 ¹² BTU	PACE
DEBARKING ROUNDWOOD	64.0	27.0	26.2	29.2	29.2	28.4	26.0	.97	1	.97	.90	204	BURN ALL BARK HEAT RECOVERY AND COGENERATION POWER & STEAM P.S. = 200 (10 ¹²) BTU
CHIPPING FOR KRAFT PULPING	58.5	22.7	22.4	24.6	24.6	24.2	24.2	.99	1	.98	1	23	
GRINDING AND GROUNDWOOD BLEACHING	5.5	31.1	19.3	32.3	32.3	20.9	20.9	.62	1	.65	1	21	
KRAFT PULPING	58.5	51.0	42.6	49.1	49.1	31.5	27.1	.84	1	.64	.86	1287	
KRAFT BLEACHING	31.8	19.5	16.4	19.8	19.6	18.0	18.0	.84	.99	.91	1	57	
PAPERMAKING	64.0	21.1	16.4	20.0	20.0	18.0	18.0	.77	1	.90	1	128	
WORK CONTENT OF PRODUCT												1280	
TOTAL WORK ACCOUNTED												2915	

D. Olefins and Derivative Products

Olefins and derivative products industry as it was examined in this study included the coproduction of ethylene (the principle product), propylene, and butadiene and the subsequent production of the principle products derived from these olefins - polyethylene, polyvinyl chloride, polystyrene and styrene butadiene rubber. The energy consumption profile for this sector is presented in Table III-4. The input data was derived from references 1 and 4.

No significant energy saving alternatives to the existing processes were noted. Small savings are possible in derivative production by cogenerating steam and shaft power. Current production of ethylene is based on the use of feedstocks with high form value. Alternative processing is being considered which will enable the use of lower form value feedstocks.

INDUSTRY OLEFINS & DERIVATIVE PRODUCTS

BASE YEAR 1974

TABLE III-4

TOTAL PRODUCTION 23.4×10^9 #/YR
ETHYLENE

TOTAL ENERGY CONSUMED $.985 \times 10^{15}$ BTU/YR ETHYLENE
PLUS POLYMERIZATION & FINISHING REQUIREMENTS
 $\approx .200 \times 10^{15}$ BTU/YR

PROCESS DESCRIPTION	TP 10^9 LB YR	ET 10^3 BTU LB	EUSE 10^3 BTU LB	B _{IN} 10^3 BTU LB	B _{MIN} 10^3 BTU LB	BUSE 10^3 BTU LB	B _{UT} 10^3 BTU LB	η	U_1	ϵ	U_2	L(TP) 10^{12} BTU YR	PAGE
ETHYLENE PRODUCTION	23.4	42.1	27.7	42.1		27.7	27.7	.66		.66	1	337	
POLYETHYLENE HIGH & LOW DENSITY	9.4	29.7	20.2	28.4	27.8	19.6	19.6	.68	.98	.71	1	77	COGENERATION ELECT. & STEAM P.S. = 5.6×10^{12} BTU YR
POLYVINYL CHLORIDE	4.3	12.5	7.7	12.1	10.1	7.8	7.8	.61	.83	.77	1	19	COGENERATION ELECT, & STEAM P.S. = 8.6×10^{12} BTU YR
POLYSTYRENE	3.1	22.6	17.9	22.2	20.2	17.8	17.8	.79	.91	.88	1	14	COGENERATION ELECT. & STEAM P.S. = 6.2×10^{12} BTU YR
SBR RUBBER	3.5	29.8	27.5	28.7	27.5	26.5	26.5	.92	.96	.96	1	8	COGENERATION ELECT. & STEAM P.S. = 4.2×10^{12} BTU YR
WORK CONTENT OF PRODUCT												648	
TOTAL WORK ACCOUNTED												1103	

E. Aluminum

The energy consumption profile for the aluminum industry is presented in Table III-5. All input data was derived from reference 1 and personal communications with industry. Data was adjusted to a 1973 reference year. Available statistics indicated that 21% of the total aluminum production results from the reprocessing of scrap. The balance results from primary production of virgin aluminum. It was assumed that all metal processed experiences reheat in the preparation of mill products.

The principle potential energy conservation target areas which were noted for the aluminum industry are:

- 1) Reduction of cell voltage losses in the Hall process.
- 2) Use inert electrodes in the Hall process.
- 3) Raise steam with waste heat boilers.
- 4) Minimize sensible heat losses with outgoing product.
- 5) Improve overall effectiveness of reheat furnaces. Consider use of topping cycle with reheat furnace.

INDUSTRY ALUMINUM

BASE YEAR 1973

TABLE III-5

TOTAL PRODUCTION 4.5×10^6 TONS
PLUS 1.2×10^6 TONS SECONDARY

TOTAL ENERGY CONSUMED 1.39×10^{15} BTU

PROCESS DESCRIPTION	TP $\frac{10^6 \text{ TONS}}{\text{YR.}}$	ET $\frac{10^6 \text{ BTU}}{\text{TON}}$	EUSE $\frac{10^6 \text{ BTU}}{\text{TON}}$	B _{IN} $\frac{10^6 \text{ BTU}}{\text{TON}}$	B _{MIN} $\frac{10^6 \text{ BTU}}{\text{TON}}$	B _{USE} $\frac{10^6 \text{ BTU}}{\text{TON}}$	B _{UT} $\frac{10^6 \text{ BTU}}{\text{TON}}$	η	U_1	ϵ	U_2	L(TP) $\frac{10^{12} \text{ BTU}}{\text{YR}}$	PACE
ANODE COKE PRODUCTION	4.5	18.3	17.3	17.6	17.5	16.4	15.2	.95	1	.93	.94	10.8	RECOVER SENSIBLE HEAT IN OUTGOING PRODUCT
ANODE BAKING	4.5	25.5	14.1	24.3	24.3	14.2	13.2	.55	1	.59	.93	49.9	RECOVER SENSIBLE HEAT IN OUTGOING PRODUCT
ALUMINA REFINING (BAYER PROCESS)	4.5	7.4	0.1	7.1	2.7	0	0	.01	.38	0	1	31.9	RAISE STEAM WITH WASTE HEAT BOILERS P.S. = $19.8(10^{12})$ BTU
ALUMINA CALCINING	4.5	10.0	7.7	9.1	9.1	4.2	0	.77	1	.46	0	41.0	RAISE STEAM WITH EXHAUST PRODUCT
ELECTROLYTIC REDUCTION (HALL PROCESS)	4.5	183.3	33.9	184.6	184.6	33.9	27.8	.19	1	.18	.82	705.6	REDUCE CELL VOLTAGE BY 10% P.S. = $76.5(10^{12})$ BTU USE INERT ELECTRODE P.S. = $110.0(10^{12})$ RECOVER OFF-GAS P.S. = $27.5(10^{12})$
SECONDARY PROCESSING	1.2	8.4*	4.0	8.4	8.4	3.0	0	.48	1	.38	0	10.1	RECOVER HEAT FROM PRODUCT
PRODUCT REHEAT	5.7	52.6	15.8	52.6	33.9	5.9	0	.30	.64	.17	0	300.0	EXHAUST HEAT RECOVERY IMPROVED INTERNAL HEAT TRANSFER EFFECTIVENESS REDUCE HEAT LOSSES TOPPING CYCLE P.S. = 100×10^{12} BTU
WORK CONTENT OF PRODUCT												125	
TOTAL WORK ACCOUNTED												1273	

*FUEL VALUE OF ALUMINUM FEEDSTOCK NOT INCLUDED

F. Textiles

The energy consumption profile for the textile industry is shown in Table III-6. The specific input data was derived from data found in reference (4). To an extent much greater than the other industries studied, the textile industry is very diffuse in terms of the variety of products, the numbers of plants producing these products and the diversity of processes employed in production. It has been estimated that there are more than 7,200 establishments within the U.S. producing and finishing various textile mill products. The products produced by these industries are classified in nine three digit SIC categories. Very generally, the types of goods produced fall into two categories knit and woven. Woven goods represents approximately 64% of the total production while knit goods represent the balance. Two thirds of the total energy consumed in textile manufacture is used in three finishing processes (i.e. greige goods preparation, dyeing and fabric finishing). The balance of the energy consumption is used in yarn manufacture, weaving plant, air conditioning and miscellaneous requirements. The energy consumption profile analysis was limited to the three finishing operations as they apply to knit and woven fabrics. A total of six process units were considered.

Most of the energy consumed in textile finishing is used for raising steam which is subsequently used for heating water with almost a complete loss of availability. Direct firing of gas in the tenterframe dryers represents the next largest consumption. Electrical drive power is also significant.

The principle potential energy conservation target areas which were noted for the textile industry are:

- 1) Cogenerate electrical power and steam. Steam from the back pressure turbine can be used directly and to heat process water.
- 2) Reduce water consumption by using recycling techniques.
- 3) Employ more effective water extraction techniques.
- 4) Incorporate heat recovery on tenterframe dryers and optimize exhaust flow rates.

INDUSTRY - TEXTILE

BASE YEAR 1973

TABLE III-6

TOTAL PRODUCTION 11.5×10^9 #/YR

TOTAL ENERGY CONSUMED $.54 \times 10^{15}$ BTU/YR

PROCESS DESCRIPTION	TP $\frac{10^9 \text{ LB}}{\text{YR}}$	ET $\frac{10^3 \text{ BTU}}{\text{LB}}$	E _{USE} $\frac{10^3 \text{ BTU}}{\text{LB}}$	B _{IN} $\frac{10^3 \text{ BTU}}{\text{LB}}$	B _{MIN} $\frac{10^3 \text{ BTU}}{\text{LB}}$	B _{USE} $\frac{10^3 \text{ BTU}}{\text{LB}}$	B _{UT} $\frac{10^3 \text{ BTU}}{\text{LB}}$	η	U_1	ϵ	U_2	L(TP) $\frac{10^{12} \text{ BTU}}{\text{YR}}$	PACE
PREPARATION - KNIT	4.14	2.5	2.4	2.5	.5	.2	0	.96	.24	.33	0	10.4	USE LOW QUALITY INPUT. REDUCE WATER THROUGHOUT P.S. = 7×10^{12} BTU
DYE - KNIT	4.14	7.8	7.3	7.8	2.5	1.1	0	.93	.32	.44	0	32.3	USE LOW QUALITY INPUT STEAM P.S. = 19×10^{12} BTU
FINISH - KNIT	4.14	3.8	2.4	3.8	2.5	.6	0	.63	.66	.24	0	15.7	REDUCE TENTER FRAME EXHAUST. ADD HEAT RECOVERY SYSTEM P.S. = 2×10^{12} BTU
PREPARATION - WOVEN	7.36	24.7	23.6	24.7	6.9	1.7	0	.96	.28	.25	0	181.8	USE LOW QUALITY INPUT STEAM. ADD HEAT RECOVERY SYSTEM P.S. = 129×10^{12} BTU
DYE - WOVEN	7.36	13.9	12.9	13.9	4.7	1.7	0	.93	.34	.36	0	102.3	USE LOW QUALITY INPUT STEAM. ADD HEAT RECOVERY SYSTEM P.S. = 63.4×10^{12} BTU
FINISH - WOVEN	7.36	3.6	2.7	3.6	2.3	1.6	0	.75	.55	.80	0	26.5	USE LOW QUALITY INPUT STEAM. ADD HEAT RECOVERY SYSTEM P.S. = 12×10^{12} BTU
TOTAL LOST WORK ACCOUNTED												369	

G. Cement

The energy consumption profile for the cement industry is presented in Table III-7. The input data was derived from referenced 2, 4, 5 and 6. All data were adjusted to a 1974 reference year. The total energy consumed by the cement industry in the U. S. indicates that the specific energy consumption (BTU/ton) is higher than world average and substantially higher than "par" for modern equipment. This is evidently due to the fact that most U. S. equipment was built and installed when energy supplies were cheap and seemed limitless and that there has been little expansion in the industry in recent years. Cement processing falls into two general categories, wet processing and dry processing. Approximately 58% of the total U. S. production employs a wet process, the balance employs dry processing. Some dry processes are now being equipped with preheaters which enhance overall efficiency. There are approximately 434 cement kilns operating - 251 wet process kilns, 148 dry process kilns and 35 dry process with preheater kilns. The process units selected for analysis encompassed feedstock preparation, clinkering and finish grinding steps.

The principle energy conservation target areas in the cement industry are:

- 1) Use of waste heat to dry feed stocks.
- 2) Convert wet processes to dry processes in those regions where the nature of the feedstock permits such change.
- 3) Add suspension preheaters to dry process units.
- 4) Improve overall efficiency of finish grinding and classification systems.

INDUSTRY CEMENT

BASE YEAR 1974

TABLE III-7

TOTAL PRODUCTION 77.7 x 10⁶ TONS

TOTAL ENERGY CONSUMED .528 x 10¹⁵ BTU

PROCESS DESCRIPTION	TP 10 ⁶ TONS YR	ET 10 ⁶ BTU TON	EUSE 10 ⁶ BTU TON	BIN 10 ⁶ BTU TON	BMIN 10 ⁶ BTU TON	BUSE 10 ⁶ BTU TON	BUT 10 ⁶ BTU TON	η	U ₁	E	U ₂	L(TP) 10 ¹² BTU YR	PACE
QUARRYING CRUSHING MIXING (WET)	45.0	.179	-	.179	.179	0	0	-	1	-	1	8.1	
QUARRYING CRUSHING MIXING (DRY)	32.7	.870	.061	.870	.510	.013	0	.07	.59	.03	0	28.5	DRY FEED WITH LOW QUALITY HEAT P.S. = 11.8 x 10 ¹²
CLINKERING & COOLING (WET)	45.0	5.60	5.20	5.60	5.60	1.60	.38	.93	1	.49	.55	184.5	CONVERT TO DRY PREHEAT PROCESS P.S. = 76.5 x 10 ¹²
CLINKERING & COOLING (DRY)	26.4	4.92	4.67	4.92	4.92	.68	.38	.95	1	.37	.83	90.3	ADD PREHEATER P.S. = 35.6 x 10 ¹²
CLINKERING & COOLING (DRY WITH PREHEAT)	6.3	3.57	3.49	3.57	3.57		.38	.98	1			20.1	
FINISH GRINDING	77.7	1.14	.38	1.14	.99	.38	.38	-	.87			59.1	IMPROVE GRINDING AND CLASSIFICATION EFFICIENCY P.S. = 11.7 x 10 ¹²
WORK CONTENT OF PRODUCT												29.5	
TOTAL WORK ACCOUNTED												420.1	

H. Glass Industry

The energy consumption profile for the glass industry is presented in Table III-8. The input data was derived from references 1 and 2. All data were adjusted to 1973 reference year. It was assumed that all glass products have an energy consumption profile similar to the glass container industry which in itself consumes 60% of the total energy consumed in this industrial sector. The production of synthetic soda ash and coke were considered to be processes directly related to the glass industry because large quantities are used as feedstocks and both materials are energy intensive.

The principle energy conservation target areas in the glass industry are:

- 1) The melting furnace which is internally inefficient and makes poor use of output availability.
- 2) The production of synthetic soda ash.
- 3) The finishing operations which appear to use energy resources inefficiently and recover little if any of the output availability.

INDUSTRY-GLASS

BASE YEAR 1973

TABLE III-8

TOTAL PRODUCTION 18.4×10^6 TONS

TOTAL ENERGY CONSUMED 334×10^{12} BTU

PROCESS DESCRIPTION	TP $\frac{10^6 \text{ TONS}}{\text{YR}}$	E _T $\frac{10^6 \text{ BTU}}{\text{TON}}$	E _{USE} $\frac{10^6 \text{ BTU}}{\text{BTU}}$	B _{IN} $\frac{10^6 \text{ BTU}}{\text{TON}}$	B _{MIN} $\frac{10^6 \text{ BTU}}{\text{TON}}$	B _{USE} $\frac{10^6 \text{ BTU}}{\text{TON}}$	B _{UT} $\frac{10^6 \text{ BTU}}{\text{TON}}$	η	U_1	ϵ	U_2	L(TP) $\frac{10^{12} \text{ BTU}}{\text{YR}}$	PACE
COKE PRODUCTION	18.4	4.6	4.4	4.8	4.8	4.32	4.0	.96	1	.9	.93	14.7	UTILIZE BY-PRODUCT FUELS P.S. = $5.5(10^{12})$ BTU
SYNTHETIC SODA ASH PRODUCTION (SOLVAY PROCESS)	18.4	4.0	.1	3.4	3.4	.1	.1	.03	1	.03	1	60.7	USE 100% NATURAL SODA ASH P.S. = $61(10^{12})$ BTU
MELTING WITH REGENERATION	18.4	8.8	4.3	7.6	7.6	2.0	0	.48	1	.26	0	139.8	PREHEAT FEED WITH COMBUSTION PRODUCT EXHAUST P.S. = $18.4(10^{12})$ BTU
REFINING FORMING ANNEALING	18.4	5.4	1.6	5.4	5.4	1.1	0	.30	1	.20	0	99.4	RECOVER 30% OF CURRENT HEAT LOSSES P.S. = $.33(10^{12})$ BTU
TOTAL WORK ACCOUNTED												314.6	

IV. Ranking of Process Units

The process units identified and analyzed for the eight energy intensive industries have been ranked in order of descending lost work and listed in that order in Table IV-1. Table IV-1 ranks the process unit, shows the industry sector where it is found, and quantifies the total lost work. In addition, the potential saving of lost work is shown. Where a relationship exists between a given process unit and other process units (in the sense that a specific process improvement applies to several process units) this relationship is shown in the last column of Table IV-1.

Related processes were then grouped and re-ranked with unrelated processes as shown in Table IV-2. This tabulation is more meaningful for planning purposes because it shows the total availability loss resulting from specific equipment or process insufficiencies. The accumulated potential saving of lost availability for each related group of processes is also shown in Table IV-2 together with a general description of the process alternative required to achieve the saving potential.

The largest single loss of available work as well as the largest single potential saving of lost availability results from a group of related process units in the petroleum industry. All of these processes employ a similar heater component to preheat feedstocks entering the various reaction zones of the process units. The heaters are basically inefficient because they burn primary fuel (usually natural gas) to heat feedstocks to relatively low temperatures - less than 800°F. In addition to the large loss of availability at the front end of the heater, significant availability losses also occur as the products of combustion are exhausted at elevated temperature (generally in excess of 500°F).

Although the textile process units as a group rank sixth in terms of lost availability, they rank second in terms of potential for process improvement. Large availability losses occur in textile finishing for raising low pressure steam and for direct fire air heaters. Technically, substantial improvements are possible in both areas.

The Kraft pulping paper process independently ranks second in terms of total availability loss and fourth in terms of potential for improvement. The losses result primarily from the ineffective use of the black liquor waste product stream. Combustible materials contain in this stream are currently burned to raise low pressure steam. Cogeneration of electrical power and steam would result in a substantial reduction of "lost availability". Such a hybrid system seems particularly appropriate since large quantities of electrical power are currently purchased by papermills.

Potential savings of lost availability was not quantified for all processes in the ranking tables. This is not to suggest that improvements are not possible but that specific alternatives were not uncovered during the limited scope of this survey.

Table IV-1

Process Unit Ranking
By Total Lost Work

Rank	Process Unit	Industry	L(TP) <u>10¹² BTU</u> Year	P.S. <u>10¹² BTU</u> Year	Related Process
1	Kraft Pulping	Paper	1,287	200	
2	Atmospheric Distillation	Petroleum	869	225	7, 16, 26, 35, 25
3	Electrolytic Reduction	Aluminum	706	214	
4	Iron Production	Steel	611	67	
5	Coke Production	Steel	442	141	45
6	Ethylene Production	Olefins & Derivatives	337		
7	Catalytic Reforming	Petroleum	325	108	2, 16, 26, 35, 25
8	Product Reheat	Aluminum	300	59	
9	Catalytic Cracking	Petroleum	278		
10	Alkylation	Petroleum	252		
11	Debarking Roundwoods	Paper	204	150	
12	Clinkering & Cooling (Wet)	Cement	185	76	27, 42
13	Preparation Woven Fabric	Textile	182	129	23, 37, 40 44, 47
14	Open Hearth Steel	Steel	179		
15	Product Reheat	Steel	172		
16	Vacuum Distillation	Petroleum	168	42	2, 7, 26, 35, 25
17	Glass Melting with Regeneration	Glass	140	18	

Table IV-1 (Con'd)

Process Unit Ranking
By Total Lost Work

Rank	Process Unit	Industry	L(TP) <u>10¹² BTU</u> Year	P.S. <u>10¹² BTU</u> Year	Related Process
18	Ore Preparation	Steel	130	2	
19	Papermaking	Paper	128		
20	Basic Oxygen Furnace	Steel	122	22	
21	Blast Furnace Air Preheater	Steel	114	(67)	
22	Coking	Petroleum	107		
23	Dyeing Woven Fabric	Textile	102	63	13, 37, 40, 44, 47
24	Refining Forming Annealing	Glass	99	33	
25	Hydrocracking	Petroleum	96	21	27, 16, 26, 35
26	Naptha Desulfurization	Petroleum	95	50	2, 7, 16, 35, 25
27	Clinkering & Cooling (Dry)	Cement	90	36	12, 42
28	Polyethylene Production	Olefins & Derivatives	77	6	
29	Grinding & Groundwood Bleach	Paper	63		
30	Synthetic Soda Ash Production	Glass	61	61	
31	Finish Grinding	Cement	59	12	
32	Kraft Bleaching	Paper	57		
33	Electric Furnace Steel	Steel	51		
34	Anode Baking	Aluminum	50		

Table IV-1 (Con'd)

Process Unit Ranking
By Total Lost Work

Rank	Process Unit	Industry	L(TP) <u>10¹² BTU</u> Year	P.S. <u>10¹² BTU</u> Year	Related Process
35	Isomerization	Petroleum	43	13	2, 7, 16, 26, 25
36	Alumina. Calcining	Aluminum	41		
37	Dyeing - Knit Fabric	Textile	32	19	13, 23, 40, 44, 47
38	Alumina. Refining	Aluminum	32	20	
39	Quarrying Crush- ing Mixing (Dry)	Cement	28	12	
40	Finishing Woven Fabric	Textile	27	12	13, 23, 37, 44, 47
41	Wood Chipping for Kraft Pulp	Paper	23		
42	Clinkering & Cool- ing Dry with Pre- heat	Cement	20		12, 27
43	PVC Production	Olefins & Derivatives	19	9	
44	Finishing Knit Fabric	Textile	16	2	13, 23, 37, 40, 47
45	Coke Production	Glass	15	5	5
46	Polystyrene Prod.	Olefins & Derivatives	14	6	
47	Preparation Knit Fabric	Textile	10	7	13, 23, 37, 40, 44
48	Secondary Pro- cessing	Aluminum	10		
49	Anode Coke Prod.	Aluminum	10		
50	Quarrying Crushing Mixing (Wet)	Cement	8		
51	SBR Production	Olefins & Derivatives	8	4	

Table IV-2

INDIVIDUAL PROCESS UNITS AND
RELATED PROCESS UNIT GROUPS RANKED
BY TOTAL LOST WORK

Rank	Process Unit	Industry	L(TP) <u>10¹² BTU</u> Year	P.S.	PACE
1	Atmospheric Distillation	Petroleum	869	225	
	Catalytic Reforming	Petroleum	325	108	
	Vacuum Distillation	Petroleum	168	42	
	Hydrocracking	Petroleum	96	21	
	Naptha Desulfurization	Petroleum	95	50	
	Isomerization	Petroleum	43	13	
2			1,596	459	Topping Cycle Recuperation
2	Kraft Pulping	Paper	1,287	200	Heat Recovery Cogeneration
3	Electrolytic Reduction	Aluminum	706	214	Inert Electrode, Reduce Cell Voltage, Recover Gas
4	Iron Production	Steel	611	67	Increase Air Blast Temp.
5	Coke Production	Steel	442	141	
	Coke Production	Glass	15	5	
			457	146	Heat Recovery By Dry Quenching
	Preparation Woven Fabric	Textile	182	129	
	Dyeing Woven Fabric	Textile	102	63	
	Dyeing Knit Fabric	Textile	32	19	

Table IV-2 (Con'd)

INDIVIDUAL PROCESS UNITS AND
RELATED PROCESS UNIT GROUPS RANKED
BY TOTAL LOST WORK

Rank	Process Unit	Industry	L(TP) <u>10¹² BTU</u> Year	P.S.	PACE
	Finishing Woven Fabric	Textile	27	12	
	Finishing Knit Fabric	Textile	16	2	
	Preparation Knit Fabric	Textile	10	7	
6			369	232	Use Low Quality Waste for Water Heating Recupera- tion on Dryer
7	Ethylene Pro- duction	Olefins & Derivatives	337		
8	Product Reheat	Aluminum	300	100	Recuperation Loss Reduction Topping Cycle
	Clinkering Cooling (Wet)	Cement	185	76	Convert to Dry Process
	Clinkering Cooling (Dry)	Cement	90	36	Add Preheaters
	Clinkering Cool- ing (Dry with Preheat)	Cement	20	—	
9			295	112	
10	Catalytic Cracking	Petroleum	278		
11	Alkylation	Petroleum	252		
12	Debarking Round- woods	Paper	204	150	Scrap Recovery
13	Open Hearth Steel	Steel	179		
14	Product Reheat	Steel	172		
15	Glass Melting	Glass	140	18	Preheat Feed
16	Ore Preparation	Steel	130	2	Charge Hot Sinter
17	Papermaking	Paper	128		

Table IV-2 (Con'd)

INDIVIDUAL PROCESS UNITS AND
RELATED PROCESS UNIT GROUPS RANKED
BY TOTAL LOST WORK

Rank	Process Unit	Industry	L(TP) <u>10¹² BTU</u> Year	P.S.	PACE
18	Basic Oxygen Furnace	Steel	122	25	Collect BOF Off-Gas
19	Blast Furnace Air Preheater	Steel	114	(67)	See Iron Production
20	Coking	Petroleum	107		
21	Refining Forming Annealing	Glass	99	33	Heat Recovery
22	Polyethylene Production	Olefins & Derivatives	77	6	
23	Grinding & Groundwood Bleach	Paper	63		
24	Synthetic Soda Ash Prod.	Glass	61	61	Use Natural Soda Ash
25	Finish Grinding	Cement	59	12	Improved Classification Equipment
26	Kraft Bleaching	Paper	57		
27	Electric Furnace Steel	Steel	51		
28	Anode Baking	Aluminum	50		
29	Alumina. Calcining	Aluminum	41		
30	Alumina. Refining	Aluminum	32	20	Low Quality Heat
31	Quarrying Crushing Mixing (Dry)	Cement	28	12	Low Quality Heat
32	Wood Chipping for Kraft Pulp	Paper	23		

Table IV-2 (Con'd)

INDIVIDUAL PROCESS UNITS AND
RELATED PROCESS UNIT GROUPS RANKED
BY TOTAL LOST WORK

Rank	Process Unit	Industry	L(TP) <u>10¹² BTU</u> Year	P.S.	PACE
33	PVC Production	Olefins & Derivatives	19	9	Cogeneration
34	Polystyrene Prod.	Olefins & Derivatives	14	6	Cogeneration
35	Secondary Processing	Aluminum	10		
36	Anode Coke Production	Aluminum	10		
37	Quarrying Crushing Mixing (Wet)	Cement	8		
38	SBR Production	Olefins & Derivatives	8	4	Cogeneration

V. Conclusions

The concept of "lost work" appears to be an accurate and easily applied measure of the total burden imposed by any given process unit on the available energy resources. This measure is universally applicable to all process units regardless of type or the industrial sector where it is found. A detailed analysis of the elements of work loss and the process work requirements reveals potential areas for improvement which may otherwise go undetected.

It is believed that the results generated during this study will be a useful tool to assist the planning and implementation of conservation activities. The scope of the survey whose results are reported herein was limited by the available budget to fifty-one process units within eight major industrial sectors. The accuracy of the results is believed to be as good as the accuracy of the process stream data found in the principle reference sources. Additional targeting effort of the type reported herein is recommended to expand the industrial field which has been examined, to refine the results which have been reported, and to define in more detail potential PACE items.

Several specific areas were identified during the survey where conservation measures could produce substantial savings, and where no orderly programs had yet been initiated. For the purpose of determining both technical and economic feasibility, detailed studies should be undertaken on the following subjects:

1) Petrochemical Plant Heaters

Determine number in use, geometry and location. Define design modification requirements and cost to increase effectiveness and thereby permit application of topping cycle. Examine integration problems associated with application of topping cycle. Determine applicability of exhaust heat recovery and define equipment requirements.

2) Kraft Pulping Waste Boilers

Determine number in use, geometry and location. Define equipment required to generate high pressure steam and back pressure turbine generator equipment.

3) Textile Mill Steam Generation

Survey steam generating equipment currently in use in textile finishing mills. Determine feasibility of cogeneration of power and steam.

4) Textile Mill Tenterframe Dryers

Survey tenterframe drying equipment to establish number in use, location, type, application etc. Examine operation to determine magnitude of saving possible through increased recirculation. Determine applicability of exhaust heat recovery and define equipment requirements.

5) Debarking Waste Utilization

Determine current practice in roundwood debarking. Define equipment requirement for combustion of waste materials and utilization of resulting thermal energy.

VI. References

- 1) Evaluation of Theoretical Potential for Energy Conservation in Seven Basic Industries prepared for the Federal Energy Administration by Battelle Columbus Labs (July 11, 1975)
- 2) The Potential for Energy Conservation in Nine Selected Industries, All Volumes, Office of Energy Conservation, Federal Energy Administration (April, 1974)
- 3) A Study of Improved Fuel Effectiveness in the Iron and Steel and Paper and Pulp Industries prepared for The National Science Foundation, Office of Energy Policy (March, 1976)
- 4) Environmental Considerations of Selected Energy Conserving Manufacturing Process Options, All Volumes, prepared for Office of Research and Development, Environmental Protection Agency
- 5) Industrial International Data Base - The Cement Industry prepared by Gordian Associates, Inc. for Office of Conservation, Energy Research and Development Administration (1976)
- 6) Concrete Manual U.S. Department of the Interior, Bureau of Reclamation (1955)
- 7) Efficient Use of Energy American Institute of Physics, AIP Conference Proceedings No. 25 (1975)
- 8) A Technical Basis for Energy Conservation Charles A Berg - Federal Power Commission, Mechanical Engineering (May 1974)