



TOGETHER
for a sustainable future

OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.



TOGETHER
for a sustainable future

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as “developed”, “industrialized” and “developing” are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

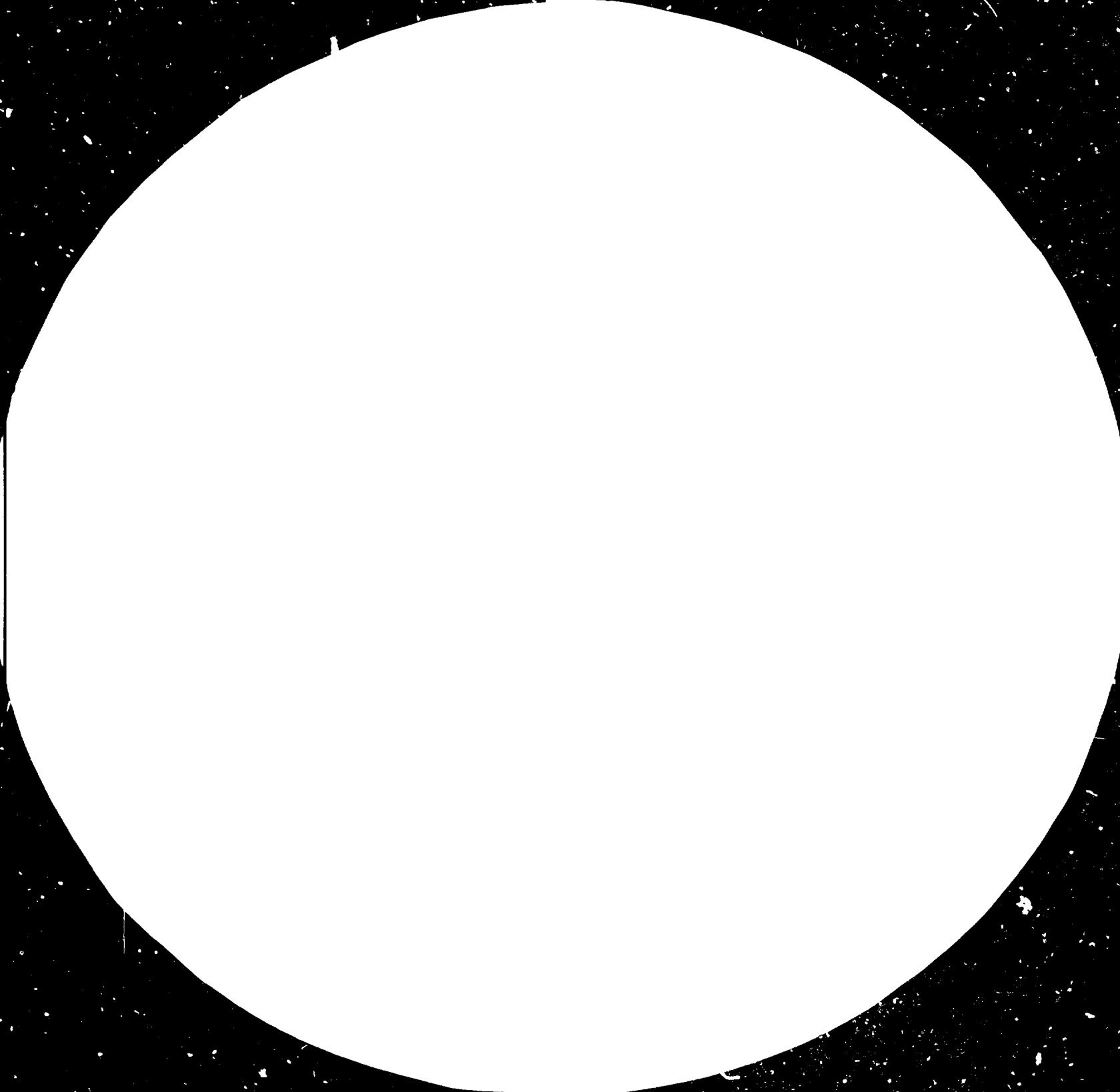
FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org





2.8



3.2



4.5



6.3



Microcopy Resolution Test Chart
NBS 1963-A

Distr.
LIMITED
ID/WG.402/6
9 August 1983
ENGLISH

12690



UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

**HIGH-LEVEL
EXPERT GROUP MEETINGS
PREPARATORY TO THE
FOURTH
GENERAL CONFERENCE
OF UNIDO**

*Energy and Industrialization
Oslo, Norway, 29 August - 2 September 1983*

T. Balabanov

**INDUSTRIAL ENERGY REQUIREMENTS
AND SOME POLICY IMPLICATIONS
FOR DEVELOPING COUNTRIES**

This paper was prepared by T. Balabanov, Consultant to the UNIDO Secretariat.

The views expressed in it are those of the author and do not necessarily reflect the views of the secretariat of UNIDO.

The designations employed and the presentation of material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

This document has been reproduced without formal editing.

CONTENTS

	<u>Page</u>
INTRODUCTION	1
1. Some Definitions Concerning Energy Utilization in the Industrial Sectors	3
2. General Pattern of Energy Utilization in the Industrial Sectors of Developing Countries	5
2.1 Pattern of final energy utilization	5
2.2 Pattern of useful energy requirements in industry	6
2.2.1 Structuring industrial energy use	7
3. Energy Aspects of Selected Processes in the Energy Intensive Industrial Sectors	8
3.1 Cement production	8
3.2 Energy consumption by the glass industry	10
3.2.1 Energy input alternatives	11
3.3 Iron and steel production	12
3.4 Textiles	15
3.4.1 Substitutability of fuel	15
3.5 Aluminum	16
3.6 Paper and allied products	19
3.7 Energy and chemicals	21
4. Energy Management Options for a Group of Plants	23
4.1 Cogeneration	23
4.2 Synergistic co-siting of industrial facilities	23
4.4 Applicable substitution technologies	25
5. Conclusions	27
6. Recommendations	29
REFERENCES	30

INTRODUCTION

It is widely recognized today that the availability and reliability of energy supply are imperative both for the allocation of capital investment in industry and for economically justified utilization of the existing industrial capacities. Factor energy input influences industrial output mix, the location of production facilities and the technologies used for production especially for the industrial sectors having fuel costs as a substantial proportion of the total cost: cement (22 per cent), inorganic chemicals (19 per cent), iron and steel (17 per cent), textile finishing (13 per cent), building bricks (13 per cent), glass (12 per cent), paper and board (10 per cent), pottery (7 per cent), etc.^{a/}.

The negative effects of high energy prices can be partly offset if it becomes technically and economically possible to substitute other factors of production, such as capital or labour for the high-priced energy forms or other locally available fuels and cheaper electricity for high-priced petroleum.

To allow the decision makers to explore the potential for transition to domestically or regionally available energy sources, an understanding of how industry uses energy should be developed. Knowledge about the quality and composition of energy requirements, related to different industrial sectors, in "end-use" terms applied as direct heat for furnaces, process steam, electric drive, etc., will allow the identification of the potential for substitution of the lower quality energy carriers for the higher, of abundant fuel for scarce as well as the potential for utilization of local and renewable sources such as solar thermal devices, biogas or methanol.

Some considerations suggest that the possibilities to do so in developing countries are not as extensive as those in industrial countries. The manufacturing sector of developing country economies are likely to be less flexible, with a narrower spectrum of industrial activities and fewer managers and technicians with facility in changing products and processes; detailed information about possible options and costs of substitution could be untimely or insufficient and transport network for gas or coal may not be easy to develop.

On the other hand, there are certain characteristics of developing countries, e.g. their smaller energy consuming infrastructure and their higher rates of growth, which give them, potentially at least, greater flexibility in the choice of capital stock and development strategies.

The search for alternative energy sources, therefore, and for measures to improve the efficiency of energy use is of high importance for the developing countries. Greater significance acquires also their capability to ascertain the energy implications of pursuing alternative development strategies. That has to do with the development of industrialization patterns appropriate to and consistent with the local patterns of energy availability, it includes development or adaptation of energy efficient and energy appropriate processes and products; it includes a definite consideration of non-conventional or new processes and products and it also comprises full use of comparative advantages, such as the use of abundant and cheap hydropower for production of aluminium.

a/ The figure in brackets is an estimate of the share of the fuel cost in the total cost done for the conditions in the U.K. by R.K. Cattell.

It should be stressed, that there is no simple matrix of costs and benefits for managing energy requirements in industry but, rather, that policy makers should pay attention to several levels of system management:

- (i) Choice of technology appropriate to local conditions, considering the availability of local energy supplies;
- (ii) Exploration, within the chosen technology of the possibilities for cogeneration, heat recovery, energy cascading, solar energy applications, etc. or, in other words, well conceived optimization of the energy flows throughout the production cycle;
- (iii) Consideration of several plants located in a joint industrial development area, that could lead to increased level of cogeneration of heat and electricity and energy cascading;
- (iv) Planning on the national level, elaboration of development strategies, industrial structure, product mix, centralized versus decentralized industrial development, etc.;

The first three levels mentioned above will be elaborated below in the examples of the main competing technologies in the production of cement, glass, iron and steel, textiles, aluminum and paper products. Considerations will be presented on the general pattern of energy use in industry, on the pattern, type and quantity of energy use for the main technologies of the sectors mentioned above. The analysis is undertaken with the purpose of assessing the degree of interchangeability of possible energy inputs for production of a given output and structuring the information needed for conducting such an assessment. Some energy substitution technologies common to some of the sectors will be identified as well.

1. Some Definitions Concerning Energy Utilization in the Industrial Sectors

In discussing the issues related to energy utilization in industry, a distinction must be made between the two different forms of energy, usually referred to as final energy and useful energy:

(a) Final energy is energy delivered to the final consumer, e.g. oil delivered to the industrial boiler, electricity supplied to the electric arc furnace, charcoal for blast furnaces, etc. Final energy is what the consumer buys;

(b) Useful energy - is what one actually benefits from. Most of the useful energy in industry is consumed in the form of:

- (i) Process Heat - The measure is the quantity of heat provided to the manufacturing process at various temperature levels. The service is further characterized by heat transfer medium and unit process (e.g. evaporation, distillation, direct heat, etc.);
- (ii) Feedstocks - Useful energy consumed in the form of methane, ethane, liquid petroleum gases (LPG), naphta, benzene, etc. mostly for production of industrial chemicals. Present energy inputs are natural gas, crude oil and coal;
- (iii) Mechanical Drive - Covers the devices activated by machines that yield energy in the form of rotational or translational work, e.g. electric motors, combustion engines, etc;
- (iv) Electro Process - Electrolysis, electroplating, and production processes using electric furnaces are the energy services included in this category.

Distinction should also be made among different measures of industrial energy efficiency used. One of the ways to do that is to explore the technical efficiency measures of energy utilization.

The most common measure of technical efficiency is the first thermodynamic law efficiency. The first law efficiency measures how well a piece of equipment or industrial subprocess uses a given quantity of energy. It is stated as the ratio of energy input to useful energy output. Thus the first law efficiency of a steam boiler that consumes 100 GJ of coal to produce 85 GJ of steam is 85 per cent. However this efficiency may provide a misleading impression of the enormous potential for improvement.

Many experts argue that the second thermodynamic law efficiency is a more appropriate indicator of industrial energy efficiency. The second law recognizes that the quality of energy is often more important than quantity. For example 1 kg of steam condensate at temperature 90°C has the same energy as 2 kg cooling water in a power plant at a temperature of 45°C. The hot condensate can be used for water heating while the cooling water has little further use. Technically, the second law efficiency is defined as the ratio of the least amount of energy that could have accomplished a specific task (such as production of 1 ton of steel) to the amount of energy actually required to perform the task. For example (see Table 1).

China consumed 37.0 GJ of energy for production of 1 ton of steel, while Japan's energy consumption was 19.00 GJ/t and the thermodynamic minimum has been computed to be 6.0 GJ/ton. One can clearly see the variation in the countries energy intensities. The high values in India and China are probably due to inefficient coal utilization and the low values in Japan are based on the energy consciousness prevailing in that country, but it is relevant to note that the theoretical minimum energy level can never be achieved.

Table 1. Comparison of industrial energy intensity in selected countries (1979-1981) with theoretical minimum for crude steel, cement and primary aluminum

Product	Country	Energy Intensity ^{c/} GJ/ton	Theoretical minimum energy intensity ^{a/} GJ/ton
Crude steel	Japan	19.0	6.0
	U.S.A.	26.0	
	Brazil	27.0	
	China	37.0	
	India	41.0	
Cement clinker	Japan	3.66	0.8
	U.S.A.	6.3	
	Brazil	4.39	
	China	6.04	
	India	6.3	
Primary aluminum ^{b/}	U.S.A.	190.0	25.2

a/ Based upon thermodynamic availability analysis;

Source: Gyftopoulos E.P. and al., Potential Fuel Effectiveness in Industry, Ballinger Publishing Co., 1974.

b/ Does not include effect of scrap recycling.

c/ Source: "Energy Efficiency in the Developing Countries", paper presented by the World Bank at the fourth session, Technical Energy Group, UN, 13 to 12 December 1982, New York.

In addition to the first and second law efficiencies, the technical efficiency of industrial energy use, or industrial energy intensity, is expressed in terms of Joules or kWh per unit of product manufactured (e.g. GJ per ton of steel produced or kWh electricity per ton of aluminium produced). Here (see Table 1) it is used to demonstrate the substantial scope for improvement in efficiency for crude steel and cement production in Brazil, China and India as compared with Japan and USA.

2. General Pattern of Energy Utilization in the Industrial Sectors of Developing Countries

While a lot of information is available for the pattern of final or even useful energy utilization in the developed countries, in the case of developing countries some analogies or indirect indicators have to be applied as clues about the energy use and other issues related to industrial development.

2.1 Pattern of final energy utilization

Evidence shows that the industries in most of the developing countries are still very dependent on oil and that insufficient electricity supply in some regions is hampering the introduction of up-to-date technologies. The dependence on oil of the industrial sectors of the developing countries examined in Table 2 varied between 28 and 94 per cent in the year 1980. The notable exceptions were countries such as Brazil, India and Pakistan, the lower oil dependence of their industry being a function of the availability of alternative energy resources, in particular coal and natural gas and in the case of Brazil hydro power, as well as of their long-term policy for development of those resources. For the sake of comparison only, without claiming that this ratio is close to optimal, in the U.S.A for the year 1977 the share of oil in total industrial energy consumption was 25 per cent, which is representative of several other industrialized countries.

Table 2. Oil use ratio to delivered energy in industrial sector for selected developing countries

Malaysia	0.94	Korea, Republic of	0.66	Bangladesh	0.28
Jamaica	0.87	Thailand	0.65	Brazil	0.28
Kenya	0.83	Indonesia	0.63	India	0.08
Philippines	0.74	Ethiopia	0.45	Pakistan	0.06
Panama	0.71	Mexico	0.33		

Source: World Energy Conference: Oil Substitution Task Force, August 1982.

The second important indicator of the pattern of final energy utilization is the use of electricity in industry. The place of electricity is quite distinct. Electricity is viewed not only as a means of supplying electric drive, electrolytic processes and other end-uses, but also its level of utilization serves as an indicator for the technological progress in the sector (e.g. levels of mechanization and of automation of the processes, etc.). The interruption of electricity supplies, usually occurring without warning, frequently causes substantial losses of production, particularly in the heavy industries.

A comparison of the ratio of electricity production per unit of GDP for industrialized and developing countries (see Ref. 14) shows that the average figure in the latter is at least three to four times (in some cases 20 times) lower than the respective figures in the developed countries.

One can draw the following preliminary conclusion from the above stated difference:

(a) The share of electricity utilization in developing countries is generally lower than that in the developed ones, thus allowing for relatively low level of sophistication of the respective industrial technologies;

(b) Frequently the low level of electricity generation means that developing countries cannot benefit from the economy of scale in the electricity production sector, hence charging a higher price for the electric power delivered to the consumers as well as creating conditions for low reliability of electricity supplies.

Recent experience has marked a trend towards diversification of energy sources. Industrial utilization of gas in the prospective areas is increasing and in parallel the infrastructure needed for enhanced coal utilization is in the process of development in countries with coal resources. In addition to that, substantial efforts are being devoted to the development of hydro-electric capacities in suitable sites.

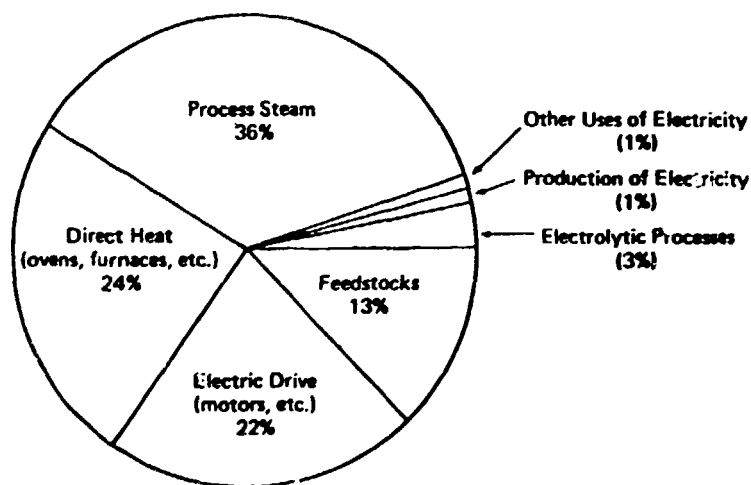
While at the final energy level one can explore the trends in energy diversification, the useful energy level reveals the potential for substitution of the energy forms as well as for more extensive exploration of the quality of energy in performing a given production task.

2.2 Pattern of useful energy requirements in industry

There are surprisingly few good data on the uses to which industry puts the energy it buys. This is due, in large measure, to the fact that even the largest industries of the developed countries until recently did not keep record of how energy is consumed by a particular piece of equipment or by an individual process. Figure 1 presents an estimate of the industrial energy end uses for the year 1973 in the U.S.A. which could constitute a basis for the discussion of some common futures of industrial end-use of energy.

This distribution of energy use could be considered close to the average established in the manufacturing sector of most of the developed countries.

Figure 1. Industrial energy consumption by end use in 1973 (U.S.)



Source: Derived from Marc H. Reus and Robert H. Williams, *Assessing the Potential for Fuel Conservation* (Albany, New York: Institute for Public Policy Alternatives, 1973), p. 19.

As seen from Figure 1, approximately 60 per cent of industrial energy consumption is used for thermal purposes, 24 per cent of which is used directly to provide heat in ovens, furnaces, kilns and the like and the balance of 36 per cent is used to indirectly provide heat through process steam; 27 per cent is put to different uses of electricity, e.g. electric drive (22 per cent), electrolytic processes (3 per cent), etc.; and the remaining 13 per cent is used as "feedstock" for chemical industries.

2.2.1. Structuring industrial energy use

By far the largest general use of energy is thermal. Classification can be made on a temperature basis. End use temperature should be specified as it is an important parameter as far as the process is concerned. In this way, to a large extent, the demand for low grade heat can be disclosed. In the right circumstances, heating requirements may be cascaded, allowing energy to flow from high temperature processes to lower temperature ones thus raising the overall energy efficiency. The temperature ranges that can be used are listed in Table 3 together with other fuel uses.

Table 3. Nature of energy end use

Heat at temperature of	
a. Hot water -	less than 100°C
b. Steam	100-200°C
	200-350°C
c. Direct heat or heated gas	
	less than 100°C
	100-200°C
	200-350°C
	350-550°C
	550-1000°C
	more than 1000°C
Motive power	
a. Mobile	
c. Stationary	
Essentially electric	
Specifically electric	
Feedstock and other non-energy	

After heat, the most significant requirement of energy is for motive power. There are a few large individual consumers of motive power such as cement grinding but almost every process has an auxiliary requirement for some form of motive power. Uses can be classified in terms of whether the power unit is stationary or mobile. The latter is restricted to on-site use, purposefully excluding the energy consumption of the transport sector.

Aside from these two major requirements for heat and power, electricity satisfies other smaller needs for energy. These can be divided into two categories. First, loads which are termed "essentially electric". These are loads which at present are conveniently and efficiently (at least in comparison with other fuels) provided for by electricity and for which there is no practical substitute available, e.g. lighting and electronics. Second, loads which are termed "specifically electric". These are loads utilizing properties peculiar to electricity (i.e. properties other than

resistive heating and normal electric motive power) e.g. electrolysis and induction heating. Although specific to electricity, the loads are not "essentially electric" since, by an equipment change, the end result may be achieved by using another fuel.

The final category of fuel use is that of feedstock and other non-energy uses. Though there is some scope for using fuel first for a non-energy purpose than for its energy content (e.g. burning used lubricating oil), its extent is very limited and basically the finite fuel resources are used for one purpose or the other.

An attempt has been made above to provide a basis for methodology for systematizing the detailed information about energy end-uses in industry, which could be obtained through energy audits or from external sources. Any analysis of developing countries' industrial energy requirements performed on a technological basis, with a view either to investigate energy substitution possibilities or to discern areas where inducing change may be possible, requires a detailed breakdown of the pattern of energy use along the lines described above.

3. Energy Aspects of Selected Processes in the Energy Intensive Industrial Sectors

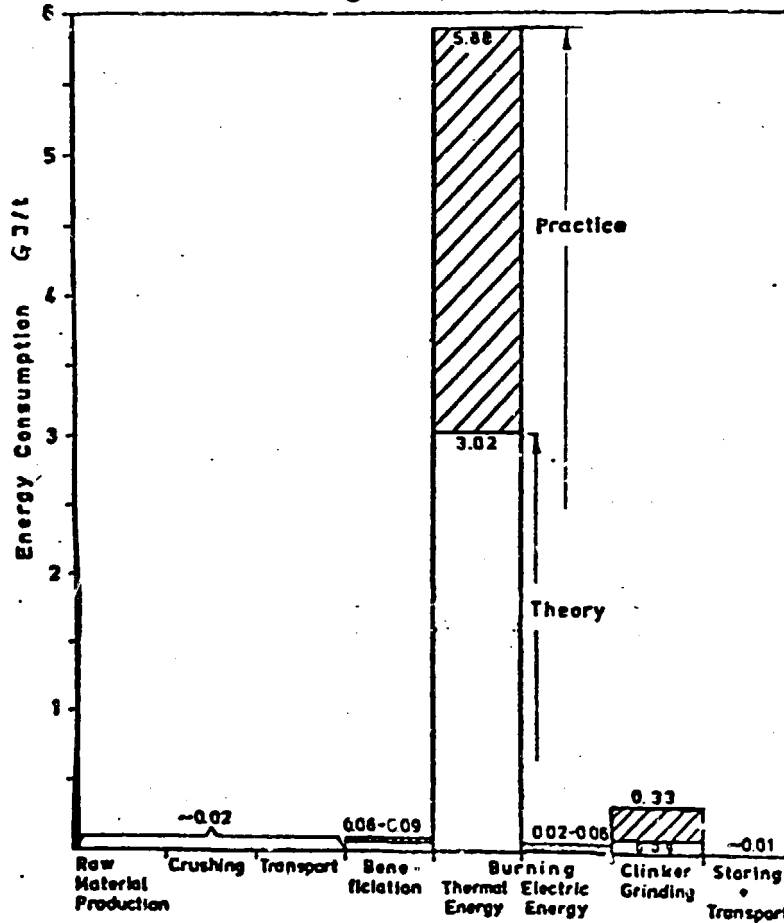
The possibility of managing energy requirements within the manufacturing sectors depends on a diversity of factors like: the choice of the "production mix", the possibility of acquiring appropriate energy efficient technologies consistent with local patterns of energy availability, the size and age of the plant, operation practice, e.g. production schedule, downtime, plant management, etc. Some considerations of the type, quantity and pattern of energy use for the main competing technologies in the production of cement, glass, iron and steel, textiles, aluminum and paper and allied products are presented below jointly with some analysis of the degree of interchangeability of the possible energy inputs used.

3.1 Cement production

Portland cement (the main industry's output) is produced by fine-grinding of portland cement clinker (main constituent) with the addition of calcium sulfate, which is necessary for setting, in the form of gypsum rock and/or anhydrous gypsum (subsidiary constituent). Portland cement clinker is produced by burning an exactly defined, finely ground and homogeneous mixture of raw materials until it is sintered. The most important raw materials for the production of cement are limestone and clay or marl.

The main process steps in the manufacturing of portland cement by the dry process with raw meal preheating and a graphic representation of the theoretical and practical energy consumption of the process are shown in Figure 2. The highest energy consumption occurs in the clinker production (burning), compared with this process step, the energy use in the others is almost negligible. Therefore, the main energy substitution efforts are concentrated in this stage; thus alternative technologies for cement production differ mainly with the design of the clinkering step, the rest of the process remaining unchanged.

Figure 2. Energy consumption for the manufacture of portland cement according to /9/



The main alternative methods for the production of cement are:

- (a) Long kiln - oil or gas fired;
- (b) Long kiln - coal fired;

(c) Rotary kiln with suspension preheater. Many modern kilns are preceded by a preheater in which hot exit gases from the kiln give up heat to the cold, incoming raw material. A number of different preheater systems are commercially available; expected savings from the use of the preheater is a 6.5 per cent reduction of the energy consumption. One variation of the suspension preheater rotary kiln is the flash calciner which has gained wide acceptance in Japan and Europe;

(d) Fluidized bed process. Here a fluidized bed reactor replaces the rotary kiln for producing clinker and uses the generation of steam as one mode of heat recovery. Any fuel can be used.

A summary of the main indicators describing the technological options for cement production is given in Table 4. A comparison of the processes shows the predominance of the heat requirements, supplied by oil, gas and coal. In the absence of cheap gas or oil, coal technologies of long kiln and fluidized bed process seem suitable for the developing countries especially that of the fluidized bed reactor where low quality coal can be used, an advantage that offsets its higher specific energy consumption.

Table 4. Summary of the main indicators for the process options in cement production (capacity 400,10³ t/yr)

Technology	Ref. Year	Specific Investment Cost \$/t	Water m ³ /t	Heat GJ/t	Electric GJ/t
Long kiln, oil fired	1975	108	1.88	4.87	0.54
Long kiln, coal fired	1975	116	1.88	4.87	0.54
Suspension preheater	1975	102	1.88	3.24	0.54
Fluidized bed reactor	1980	99	14.4	5.28	0.04

Source: Compiled from Environmental Consideration of Selected Energy Conserving Manufacturing Options, A.D. Little, Inc., Cambridge, Mass., 1976.

3.2 Energy consumption by the glass industry

On the basis of data collected by Battelle Laboratories, a breakdown of fuel usage by each unit operation has been attempted and a summary, derived from that has been drawn showing the percentage share of total energy consumed that is attributable to the four most energy intensive operations in glass container manufacture:

Energy Consumed		
Operation	(GJ/t)	Percentage
Melting	8.03	70
Refining	1.74	15
Forming	0.63	5
Post forming	1.16	10
Total	11.04	100

Using the same approach it can be shown, (see Ref. 14) for flat glass production, pressed and blown glass production, and product and purchased glass that the share of energy used in the melting step varies between 60 and 90 per cent of the total energy used.

The best a glass melting furnace can achieve is only 25 per cent thermodynamic efficiency. The remainder of the heat generated from the fuel is lost, partly in stock gases but mainly by radiation from the large areas of exposed surfaces. Glass tanks can not be regarded as completely satisfactory as long as efficiency remains low. Attempts are continuing in the direction of improvement of efficiency. Thus, the older "tongue tiles" were removed from the newer furnaces, allowing better mixing of the gas and air streams.

Electric melting of glass has greatly spread over the past 25 years. About half of the container glass manufacturers in some industrialized countries nowadays have electric boosters and at least 100 all-electric furnaces (with capacity of 4 to 140 t/day) are in service throughout the world. Electric furnaces are known to be efficient in using 65 to 80 per cent direct heating energy, compared with 15 to 20 per cent for natural gas-fired furnaces.

3.2.1 Energy input alternatives

There already exists a trend away from the use of natural gas and petroleum products by the glass manufacturers in the direction of electricity and coal. Special techniques for diversification of energy inputs are:

(a) Direct firing. Direct coal firing has the advantage of utilizing all heating value of the coal, but at the cost of considerable economic and environmental penalties e.g. sulfur dioxide emission, solid wastes like coal ash, dust from the fabric filter, etc;

(b) Coal fired hot gas generation in a conversion burner that burns all types of coals and then feeds the 1600-1700°C gases into the glass melting furnace. The system is still in a pilot stage;

(c) Coal gasification. Coal is used as a feedstock to make a low calorific gas to fire gas furnaces, a practice abandoned in about 1940. Except when operated on anthracite, the gas generated contains considerable tars, which condense in distribution headers in large quantities. Generally, the plant must be shut down every two weeks to allow burning out the deposits in the headers and distribution lines;

(d) Electric melting of glass. In gas or oil firing, heat is transferred from the flame over the glass melted through radiation emitted from the flame and the heated superstructure. Convection currents in the glass melt distribute this absorbed heat throughout the melt depth. In electric melting, the glass melt is heated directly by passing a high current through the conductive glass melt by means of electrodes inserted in the wall or bottom of the furnace.

The latest all-electric glass melting furnaces use vertically positioned molybdenum rod electrodes. The molten glass outside the electrode configuration acts as a first layer of thermal insulation to the melt, and decreases the erosion of the refractory lining of the melt tank. The power consumption in a large all-electric furnace is about 780 kWh per ton of soda-lime glass.

As mentioned above, many gas fired glass furnaces use electric boosters in order to reduce the energy consumption of the installations.

(e) Submerged combustion. Energy savings up to 50 per cent may result from placing the burners in the bottom of the glass furnace. This placement greatly improves heat transfer and causes vigorous stirring of the melt. The quality of the glass produced is poor, however, and the large number of bubbles produced requires extensive fining to produce an acceptable quality glass;

(f) Oxygen enrichment. The output of existing furnaces can be increased and the energy consumed per ton of glass reduced through oxygen enrichment of combustion air;

(g) Batch preheating. That is preheating the batch with exhaust gases from the furnaces. Thermodynamic analysis indicated that, with no heat losses from the regenerator, the batch can be preheated to 760°C with resultant reduction in fuel consumption of about 20 per cent;

(b) Float glass process. An innovation for making glass of the highest quality consists of floating the molten glass on the surface of a bath of molten tin where it spreads to a sheet of uniform thickness with an excellent fire-polished surface. A float glass train will produce several times more glass per year than a comparable unit using the older technique. Although substantial (about 50 per cent) energy savings were not the primary motivation for adopting the float process, this has been one of the many benefits of this more economical method.

In some of the unit operations, requiring low temperature heat, unsophisticated solar thermal devices can be used. Examples for such uses are:

	Energy Carrier	Temperature °C	Solar Devices
Washing and rinsing	Water	70-90	Flat plate collectors
Laminating	Air	100-180	Single tracking collectors
Drying glass fiber	Air	135-140	Single tracking collectors
Decorating	Air	20-95	Flat plate or single tracking collectors

There is in addition a high potential for heat recovery in this industry including recovery of high temperature heat from glass melting furnaces using heat wheels and low temperature heat with use of heat exchangers.

3.3 Iron and steel production

Practically all newly introduced steel making capacities are based on one of steel production routes depicted at Figure 3. Three of those production routes account for the biggest share of contemporary steel production:

- (i) Classical process, combining blast furnace (BF) with oxygen converter (OC);
- (ii) Electric arc furnace (EAF), producing steel mainly from scrap metal;
- (iii) Direct reduction (DR) plant, producing sponge iron and electric arc furnace;

Two other small scale options, not described above, but which deserve mentioning, are:

- Charcoal blast furnaces, used in Brazil, Malaysia, Argentina and Australia;
- Electric plasma furnaces, currently under development, suitable for installation in the developing countries.

In the classical process (BF+OC), as shown by Figure 4, most steel making energy is used in the blast furnace (54 per cent). Twenty per cent of total energy requirements is for forming of slabs and blooms and in hot and cold rolling, while only 11 per cent is newly introduced in the steel making furnaces. Respective energy losses are the shaded areas of the histogramme.

Figure 3. Various routes to produce steel

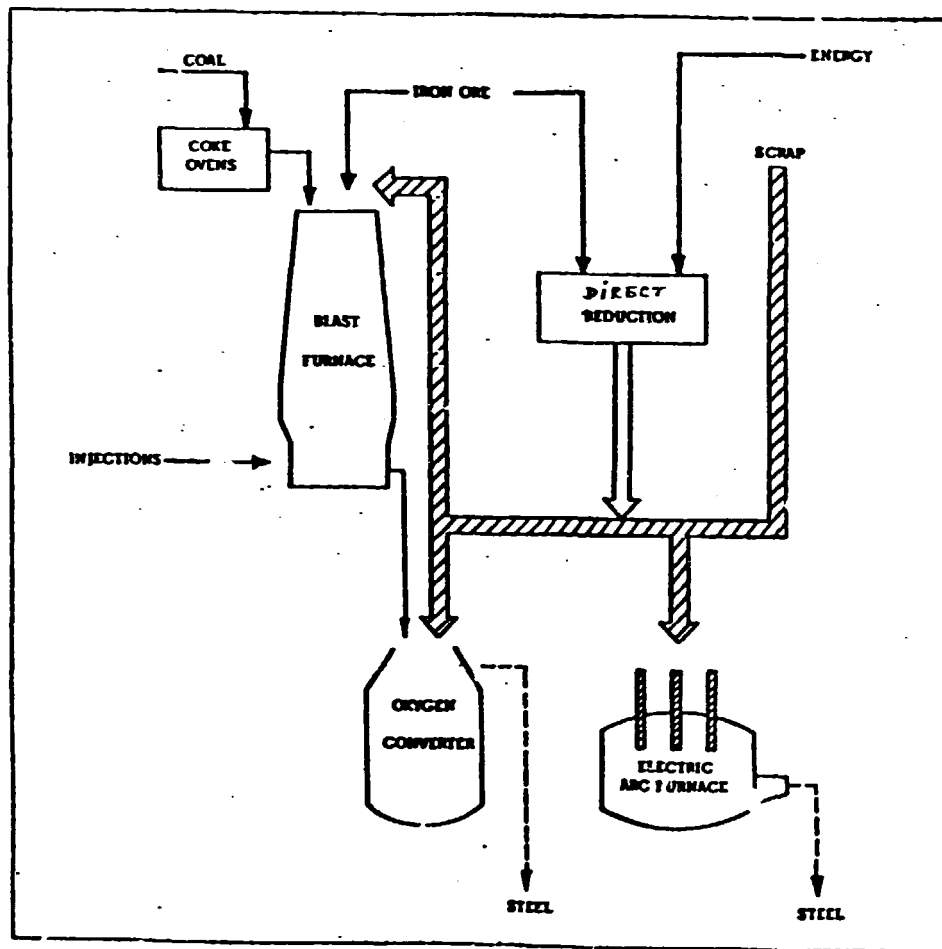
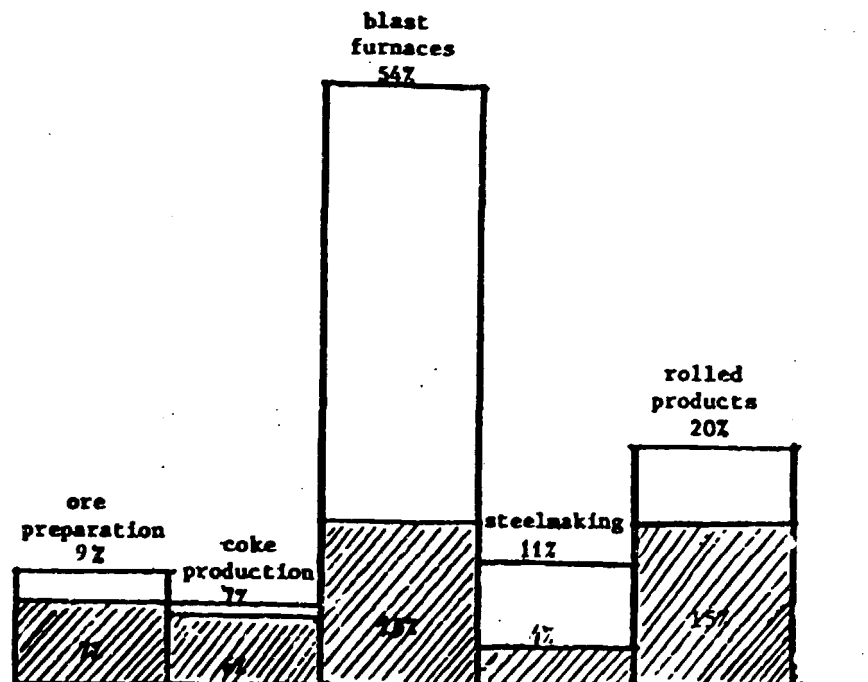


Figure 4. Distribution of energy consumption and losses^{*/} by stages in the steelmaking process, utilizing pig iron.



Source: Adapted from United Nations, Economic Commission on Europe and Energy Conservation (New York, UN, 1980) p. 58.

^{*/} Shaded areas are energy losses.

Historically, almost all energy used in the blast furnace has been coking fuel for pig iron smelting. While there exist a large energy conservation potential in the recovery of waste gases and low-grade heat for use in boilers for steam production and generation of electric power, long-term energy and substitutions must focus on the choice of technology. This choice is, in turn, affected by the fact that very little coal, either coking or non-coking, is located in most of the developing countries. Consequently, in many LDCs, the focus is not only to reduce, but to replace coke in the ironmaking blast furnace with more readily available fuels. This has been done, for example, by injecting fuel in the tuyeres and hot gas in the stack. As detailed in Table 5 the specific energy consumption rises substantially with these methods. As a result, while scarce coke is saved, more energy is actually consumed per ton of output.

Another rather energy-intensive process which is gaining popularity in developing countries is the direct reduction method. Many countries have built electric arc furnaces; furnaces which can make steel using from 100 per cent pig iron to 100 per cent scrap. But since pig iron requires large coke inputs in the blast furnaces and since scrap is generally just as scarce as coke, direct reduction of iron (DR), pioneered in Mexico, is used instead. Although more energy-intensive, direct reduction allows iron ore to be reduced by low-grade coal or gas reducers to sponge iron, which can then be charged in an electric furnace to be converted into steel. Already operating or being built in Mexico, Argentina, Brazil, India, Korea, and Venezuela, no less than twenty other developing countries have expressed interest in this "mini-plant" direct reduction method (UNIDO, 1978, p. 88). As a consequence, technological improvements in DR electric arc systems may be the most significant source of future energy conservation potential in the steel industry of developing countries.

Table 5. Energy requirements in the production of liquid steel by various processes^{a/} (10⁹ Joule/metric ton - GJ/t)

Blast furnace/OC 100 % coke)	22.6
Blast furnace/OC (coke oven gas injection)	17.95
Electric arc furnace (100 % scrap)	13.8
Fuel oil injected blast furnace/OC	20.3
Fuel oil and reformed gas blast furnace/OC	22.15
Electric arc furnace (direct reduction)	21.8

Source: UNIDO, The World Iron and Steel Industry (New York, UN, 1978), p. 167.

Also, judging from the record in several industrialized countries, intermediate-term measures such as fuller capacity utilization and increasing electric furnace and continuous casting capacity, scrap preheating, waste gas/heat recovery, fuel mixing and improvements in soaking pits, annealing and heat-treating facilities could save an additional 5 to 10 per cent of energy consumption per ton of steel output.

^{a/} Assumes a 30 per cent electricity generating efficiency.

3.4 Textiles

In general, the textile industry converts natural and synthetic fibers to fabrics. Other industries further process these fabrics into products such as apparel, upholstery, sheeting, draperies, carpets, rugs, sewing thread, tire cords, twine and rope. The textile industry thus described is included in the Standard Industrial Classification (SIC) as major group 22.

Primary process components in the textile industry are classified as: springing, texturing, weaving, knitting, greige mills, finishing-woven fabrics, finishing-knitted fabrics, yarn dyeing and floor covering. Processes in the textile industry may be subdivided into wet and dry. Yarn formation, weaving, and knitting are dry processes; wet processes include sizing, desizing, washing, dyeing, scouring, mercerizing, bleaching and various types of finishing processes.

The energy consumed per unit of production and its tentative distribution between the two forms of useful energy, namely thermal and electric for the primary processes according to a survey of the U.S. textile industry, is presented in Table 6. The data may not be fully relevant to the conditions of developing countries, but are shown to illustrate that different processes are using strongly different shares of electric and thermal energy.

Table 6. Textile processes: energy use per unit of production

Components	Energy Use/Unit of Production (MJ/kg)	Electricity Use Share (%)	Thermal Energy Share (%)
Spinning mills	17.3	93.	7
Texturing plants	15.7	95.	5
Weaving mills	14.9	60.	40.
Greige operations	31.4	70.	30.
Woven fabric finishing plants	52.1	7.	93.
Knit fabric finishing			
Knit finishing only	65.8	10.	90.
Knitting and knit finishing	45.8	40.	60.
Yarn dyeing mills	32.1	15.	85.

Source: Adapted from S.G. Cooper, The Textile Industry: Environmental Control and Energy Conservation, Park Ridge, New Jersey, Noyes Data Corp. 1978.

3.4.1. Substitutability of fuel

Electricity is used mainly to drive machinery and motors and to run air conditioning, lighting and office equipment. Fossil fuels are burnt to provide process heat and space conditioning. While electricity utilization shows an increase, fossil fuel share can be reduced through the introduction of cogeneration systems or increased participation of solar thermal devices in suitable climates.

The heat-set tenter frame dryers, which dry fabric under tension, suspend fabric in hot gas. Being in contact with the fabric, the hot gas dries it continuously. At present, natural gas is used in this process, with propane and methane being the only practical substitution fuel.

Owing to the substantial energy consumed by the heating and evaporating of water, likely areas for conservation efforts lie in the development of (1) improved heat transfer techniques, (2) effective ways to reclaim and use waste heat, (3) process equipment which requires less water, and (4) methods which facilitate the use of waste products as fuels. The listed areas present some general directions from the set of conservation options which are too numerous to be discussed here. For details one should refer to the reports by F.L. Cook, Energy Conservation in the Textile Industry, Phase I, ORO-5099-T1, and A.D. Little Inc., Environmental Considerations of Selected Energy Conserving Manufacturing Process Options, vol. 9.

Although solar devices can be used only in the auxiliary processes, thus supplying less than 10 per cent of the process energy, their perspective areas of application deserve mentioning.

The main processes where potential applications of solar thermal systems in the textile industry could be envisaged are:

	Energy Form	Temperature, °C	Solar Device
Washing	Water	70-80	Flat plate collectors
Preparation	Steam	60-115	Fixed compound surface or flat plate collect
Mercerizing	Steam	50-100	- " -
Drying	Steam	60-135	- " -
Finishing	Steam	60-150	- " -

3.5. Aluminum

Bauxite is the basic aluminum ore which is first refined into alumina (aluminum oxide) by the Bayer process. The alumina is then charged to an electrolytic reduction cell where it is reduced to molten aluminum. The conventional electrolytic process is the Hall-Heroult (H-H) smelting process. The new Alcoa chloride process is a potential replacement for H-H and has been estimated to reduce the energy consumption of smelting by 30 per cent in comparison with existing installations.

Basically, the Bayer process mixes the bauxite with caustic soda, digesting it under heat and pressure. This produces sodium aluminate dissolved in the caustic soda. The solution is cooled and seeded with crystalline hydrate, precipitating alumina trihydrate. Subsequent filtering, washing and kiln heating produce commercial alumina. An average of 2.4 tons of bauxite is required to produce 1 ton alumina.

A potential exists in this process for fuel substitution and heat recovery as well as for utilization of solar thermal devices.

The Hall-Heroult (H-H) smelting process breaks down the alumina to aluminum and oxygen (an average of 1.93 ton alumina is required to produce 1 ton aluminum). The alumina is first dissolved in molten cryolite, which acts as an electrolyte. High current passes through a suspended carbon anode, depositing aluminum at the cathode; this is syphoned off as it builds up. The oxygen from the alumina goes to the carbon anode, forming carbon dioxide. An estimate of a unit process energy requirement, covering the full production chain from mining till the end product, is given in

Table 7. The total energy requirements of the production chain from bauxite to aluminum could be calculated as:

Thermal energy - $45.7 \text{ GJ/t. alumina} \times 1.93 \text{ t. alumina/t. aluminum} + 30.55 = 118.83 \text{ GJ/t. aluminum}$
 Electric energy - $1.98 \text{ GJ/t. alumina} \times 1.93 \text{ t. alumina/t. aluminum} + 55.8 = 59.62 \text{ GJ/t. aluminum}$

Total 178.45 GJ/t. aluminum

Table 7. Energy cost per ton of aluminum (all energy units in GJ)

A. Bauxite-to-Alumina Production			B. Alumina-to-Aluminum Production		
Process	Electrical Energy	Fuel Energy	Process	Electrical Energy	Fuel Energy
Bauxite mining and preparation	0.09	4.2	Hall-Heroult electrolysis	55.8	
Bauxite grinding	1.09		Auxiliary use		13.0
Bauxite transport		3.1	Anode baking		2.8
Lime preparation from limestone	0.08		Cathode manufacture		1.05
Digestion and steam preparation		26.3	Reheat and holding furnace		8.4
Calcine alumina (direct heat)		8.4	Casting		5.3
Evaporation, pumping, etc.		3.7			
Total	1.98	45.7		55.8	30.55

Technologies to replace the Bayer process have been in the pilot plant stage for many years. These processes use high-alumina clays to produce alumina. Table 8A gives summary information on the process options in the alumina industry. The hydrochloric leaching process, nitric acid leaching, and the Toth chlorination process all employ clay of caolin as the basic material rather than bauxite. While about 4.6 tons of bauxite are required to produce 1 ton of aluminum, nearly twice that amount of clay is needed because of its lower alumina content. The necessity for relatively large amount of clay to be employed in alternative processes results in respectively higher energy requirements.

Energy consumption in the smelting process (mostly electricity) represents such a large fraction of the total energy requirement of aluminum production that it is important to examine the potential conservation measures. One possibility is a modification on the Hall-Heroult process, using titanium diboride (TiB_2) cathodes in place of the traditional carbon cathode and its iron cathode support. This can be done in existing, as well as new plants. Another option for new plants is the Alcoa chloride process. In this process alumina is chlorinated in the presence of carbon, producing aluminum chloride ($AlCl_3$), carbon dioxide, and carbon monoxide. After separation from the gases by condensation, the $AlCl_3$ undergoes electrolysis, producing liquid aluminum at the cathode. Table 8 B summarizes information comparing

traditional and modified (with TiB_2) H-H smelters, versus a new Alcoa chloride plant. Alcoa's chloride plant saves about 10 per cent of the energy in comparison with the new installations and 30 per cent in comparison with the existing ones. Information regarding integrated advanced processes, namely new Bayer/new H-H or clay chlorination/Alcoa chloride, appears in Table 8C.

Other opportunities for saving of fuels are: more efficient reheat furnaces with waste heat recovery, special insulation on ring baking furnaces used for smelter anode preparation, introduction of computer control systems to reduce temperature fluctuations in smelting operations, application of single tracking through solar collectors for steam production (215°C) in the digestion stage of the Bayer process, etc.

Process heat covers most of the requirements for refining aluminum ore into alumina. At this stage, fuel substitution and heat recovery potential exists. Electricity is the main energy input for the smelting process, transforming alumina to aluminum. Several energy saving options are feasible at this stage. The new process, Alcoa Chlorine, reduces the energy requirements of the process as indicated above.

Table 8. Process options in:

A. Alumina Industry (Basis: 700,000 tons/annum alumina production)

Process	Capital Investment 10 ⁶ US\$	Production cost US\$ ton	Energy requirements GJ/ton
Bayer (new installation)	260	235.4	15.25
Hydrochloric Acid Leaching	430	320.4	41.2
Nitric Acid Leaching	322	226.3	28.1
Clay Chlorination (Toth)	232.6	179.3	28.6

B. Aluminum Smelting Industry based on Bauxite (160,000 tons/annum)

Hall	280	1137	157.7
Alcoa Chlorine	280	1052	142
Hall with TiB_2	320	1142	157.52

C. Integrated Production of Aluminum from Ores
(basis: 160,000 tons aluminum per annum)

Bayer Alumina plus Hall	403	1372.4	172.7
Clay Chlorination plus Alcoa	296	1032	168

3.6 Paper and allied products

The paper industry involves two major energy intensive processes, wood pulping and paper forming. Wood pulping can be done by mechanical or chemical methods, or by a combination of these. A variety of pulping techniques are being used, that include among the chemical processes sulfite, kraft and soda processes, among the semichemical neutral sulfite, bisulfate and sulfate kraft, among the chemi-mechanical-Mason (exploded), Asplund (deliberated), cold soda, and hot sulfite etc. The primary function of pulping is the separation of the elongated cellulose and hemicellulose fibers and the removal of the lignin that previously bound them together. Paper forming entails the interlacing of these fibers in sheets and the subsequent removal of water by mechanical pressing and the application of heat. An overall consideration is the enormous dependence of the installations on thermal processes, primarily for lime burning, steam generation, and drying. Depending upon the specific final paper or paperboard product and the particular mill involved, the typical energy consumption for pulping plus paper forming appears to be 21 to 42 GJoules per ton of product. An energy flow diagram, shown as Figure 5, was accepted in 1977 as "reasonably representative of North American mill operations" by participants in the New Hampshire conference on energy conservation in the pulp and paper industry. According to this diagram, the energy produced internally is 52 per cent (15+37 per cent) of the gross energy used. The information in Fig. 5 is quoted from the "Survey of Applications of Solar Thermal Energy Systems to Industrial Process Heat" done by Battelle Columbus Laboratories in 1977.

A comparison of the specific energy consumption per ton of pulp, paper and board in some developed and developing countries with the best modern technology and the theoretical minimum (see Table 9) demonstrates the scope for improvement in the sector.

A number of new processes are being developed, introduced, or considered for use in industry, the major of them being Alkaline-oxygen pulping (A-O), the Rapson process and Thermomechanical pulping. Recent reports of improvements in energy use and energy recovery in the important kraft process include preevaporation of kraft black liquor by vapor recompression evaporation, the use of computer control in the recovery area of the mill and collection and treatment of kraft mill condensate. The ultimate goal for energy recovery is to achieve self-sufficiency from an energy point of view in an integrated plant.

Figure 5. Representative energy flow diagram for modern integrated paperboard mill. Thermal energy measured in Giga Joules per ton of output, and electrical energy in kWh per ton.

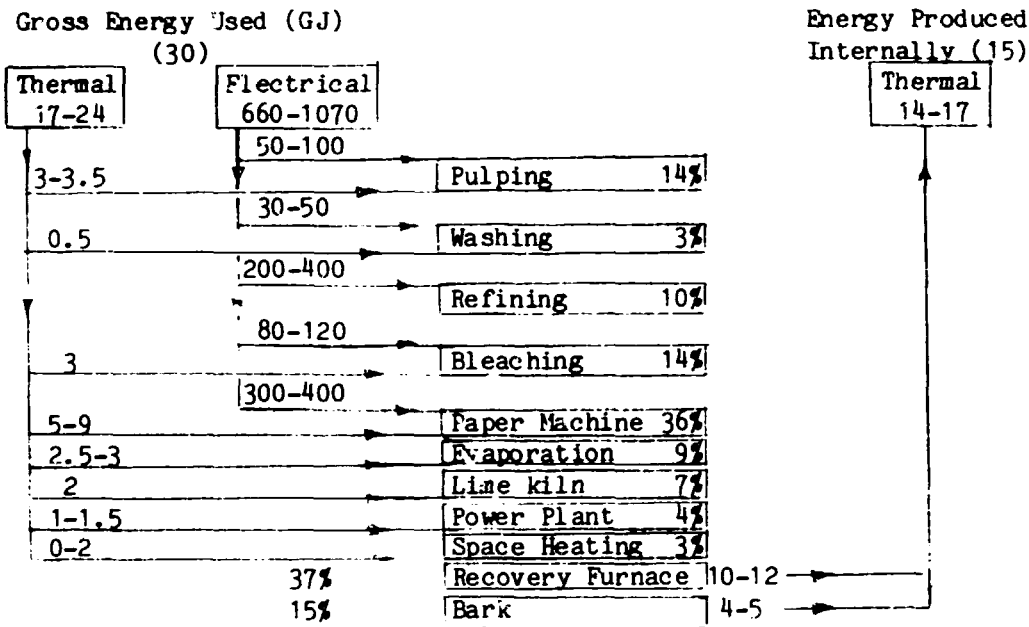


Table 9. Specific energy consumption per metric ton of pulp, paper and board (GJ/ton)

United States <u>a/</u> (1976)	
Purchased fuels	23.8
Total fuels	40.6
Canada, <u>b/</u> total fuels (1975)	
	31.6
Sweden, <u>c/</u> (1973)	
	31.65
Kenya <u>c/</u> (1977)	
	53.8
Bangladesh <u>d/</u> (1969)	
Newsprint	50.4
Writing paper	52.9
Best modern technology <u>e/</u>	27.6
Theoretical minimum <u>e/</u>	0-10

a/ John G. Myers and Leonard Nakamura, Saving Energy in Manufacturing: The Post-Embargo Record (Cambridge, MA, Ballinger, 1978) pp. 58-59.

b/ Economic Commission for Europe, The Economic Commission for Europe and Energy Conservation: Recent Experience and Prospects E/ECE/985 (New York, United Nations, 1980) p. 36.

c/ Lee Schipper and Oyuko Mbeche, "Energy Demand and Conservation in Kenya." Paper presented at Conference on Energy and Environment in East Africa, Nairobi, Kenya, 5-11 May, 1979, table 2. Estimates apparently include all fuel sources including cogeneration facilities.

d/ Meta Systems Inc. and Montreal Engineering Co., Ltd., Bangladesh Energy Study Appendix I, vol. I administered by Asian Development Bank Apparently includes internal fuel sources.

e/ Electric Power Research Institute, Efficient Electricity Use, 2nd edition, Craig Smith, ed. (New York, EPRI, Pergamon Press, 1978) p. 37.

3.7 Energy and chemicals

Most of the present energy inputs to the chemical industry are used as feedstocks, that is the useful energy consumed in the form of methane, ethane, liquid petroleum gases (LPG), naphta and benzene mostly for production of industrial organic chemicals. Present primary energy inputs are natural gas, oil and coal. Figure 6 shows the chain of materials and processes that currently provide most chemicals and polymers. The useful energy forms namely chlorine, phosphorus, aromatics, olefines, methanol, higher alcohols and chlorinated hydrocarbons, rely heavily on fossile fuels as production inputs, in most of the cases oil. The present route is therefore called petrochemical. The problem here is to find out what would be the post-petrochemical possibilities. The full set of routes, a combination of old established ones and new ones currently under development, are shown in Figure 7.

The new routes are:

- A. The conversion of methanol to liquid and gaseous hydrocarbons.
- B. The use of shale oil as a substitute in present routes using crude oil and/or coal.
- C. The anaerobic conversion of biomass to synthesis gas.
- D. The phototropic production of hydrogen in biological systems.

Old routes with increased potential:

- E. Production of hydrogen by electrolysis (use of direct nuclear heat is also being researched).
- F. Production of acetylene, possibly via carbide, but more likely through a plasma reactor.
- G. Coal hydrogenation (which also required hydrogen or synthesis gas).
- H. Fisch-Tropsch type synthesis yielding both hydrocarbons and oxygenated products.
- I. Anaerobic fermentation of natural and/or waste materials.
- J. Increased production of sugars either naturally, or by acid or enzymatic hydrolysis of cellulose; and subsequent fermentation or conversion.
- K. New products (e.g. lignin) from existing natural materials.
- L. Increased yields from existing species, and/or new or modified species.

Figure 6. Materials and processes that currently provide most chemicals and polymers

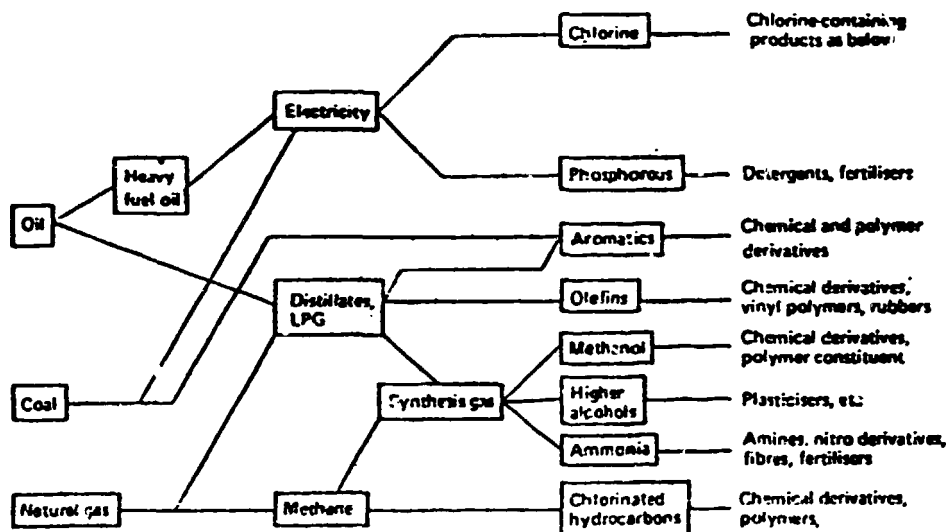
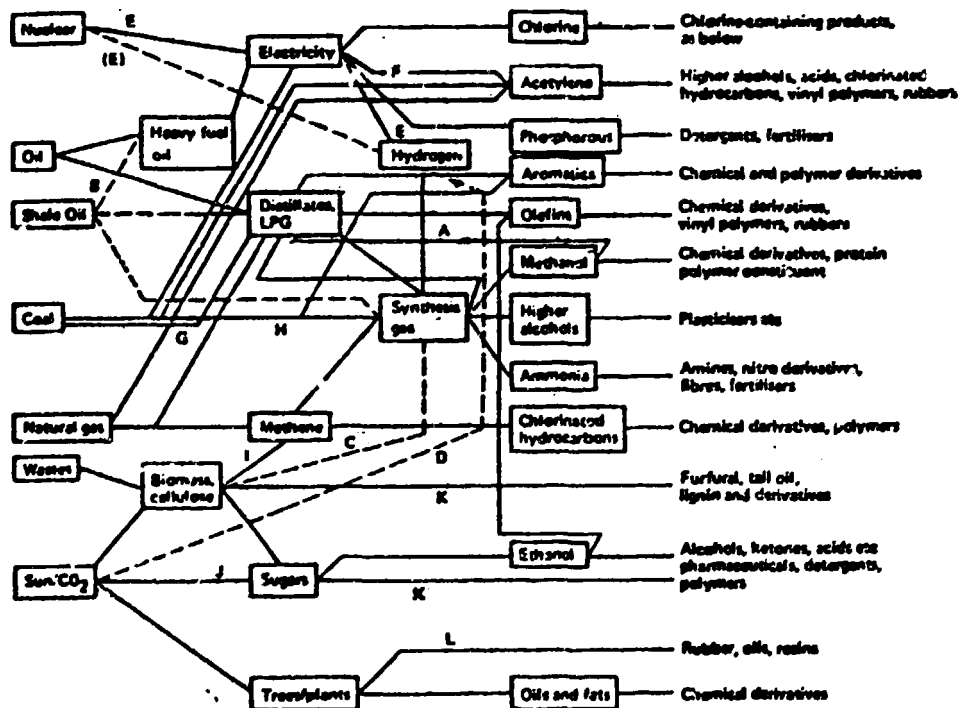


Figure 7. Potential new pathways and their relation to present and previous practice



4. Energy Management Options for a Group of Plants

The discussion so far has been concerned with the energy requirements of different processes at the plant level, as an insight to the substitutability of different energy forms within the production cycle. An extension of the boundaries of the system to include considerations for the energy management of several plants, located in an industrial development area, provides new options such as co-generation of heat and electricity and synergetic co-siting of industrial facilities. The extended boundary of the system also leads to the possibility for aggregating the experience gained so far about applicable substitution technologies common for several industrial sectors.

4.1 Cogeneration

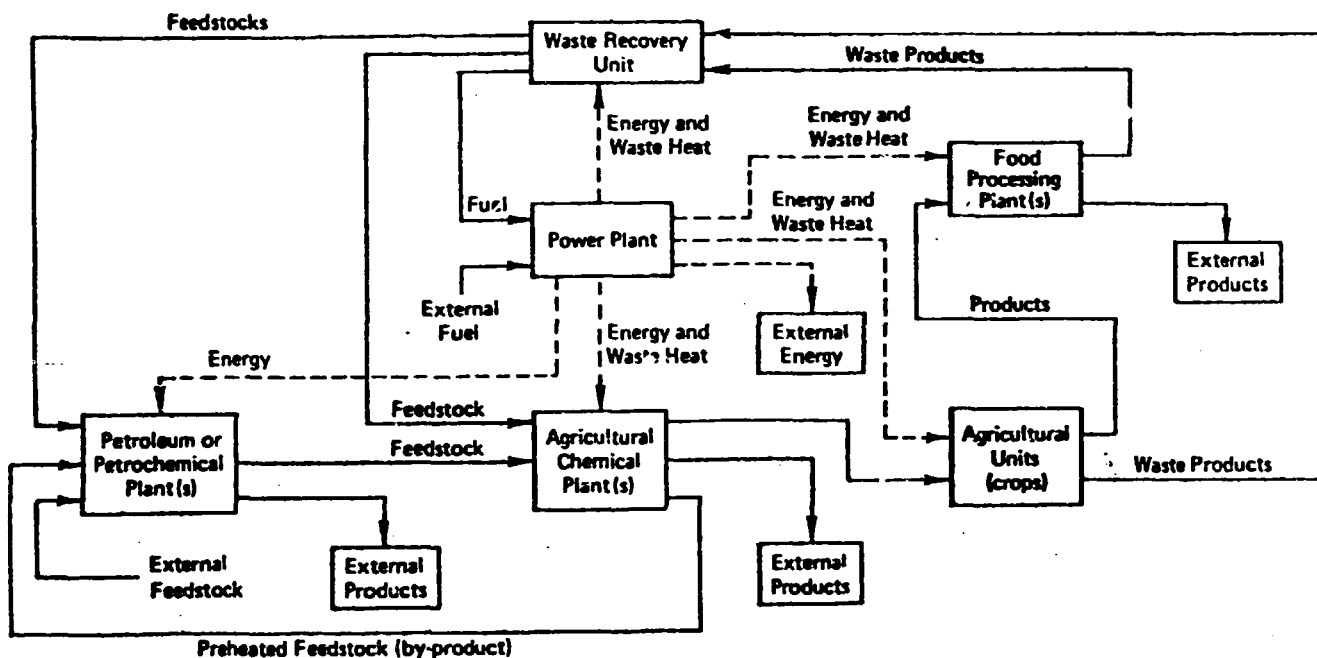
One of the most basic and important forms of energy cascading is known as "cogeneration". In cogeneration an industrial facility or group of facilities uses low quality fuel to simultaneously generate electricity and process heat or steam. Industry can produce electricity through cogeneration using one-half to two-thirds of the amount of energy required by most efficient central station utility generating plants. Experience in many countries has shown that chemical, petroleum, paper and pulp, textile and food industries have substantial inherent potential for cogeneration that could also benefit the neighbouring enterorises.

4.2. Synergistic co-siting of industrial facilities

One approach for efficient cascading of energy that has been largely ignored in some countries is the synergistic co-siting of industrial facilities in energy efficient industrial parks. Synergistic co-siting is carefully planned grouping of industrial activities, including manufacturing and processing plants, farms, small and local enterprises, and utility power plants, in order to provide access to various activities to facilities and make possible the interchange of material and energy. Figure 8 presents a hypothetical example of a synergistic co-siting situation in which a power plant, petrochemical firm, chemical plant, food-processing operation, and farm are sited together. Practice around the world has proved the workability of such an approach of transferring "energy credit" from the centralized industries to the small and local industrial enterprises. There exists sufficiently numerous combinations of the possible cascading options to make a case to case optimization of the cycle mandatory. In theory such co-siting could save enormous amounts of primary fuels, but there are some obstacles to its implementation, that could be removed by the local decision makers, for example, different industries have a different planning horizon. It may take one industry three years to build a plant while another requires eight. As a result it may be difficult for them to share a common facility. The diverse operating schedules of various industries may make it difficult or impossible to match the material and energy needs of one industry with the waste heat and material of another.

Government's role in encouraging synergistic co-siting could range from research aimed at identifying the barriers that are inhibiting synergetic co-siting and developing strategies for alleviating those barriers, to providing financial incentives for co-siting projects.

Figure 8. Hypothetical example of synergistic co-siting possibility



Source: Appalachian Regional Commission, *Study to Investigate Potential Benefits From Synergistic Co-siting of Industrial Activities* (Atlanta: Georgia Institute of Technology, September 1978), p. 7.

4.4. Applicable substitution technologies

Three major groups of energy consuming processes make use of direct combustion fuel. In these cases an adaptation to direct coal or gas use seems possible. These groups are (see also Table 10):

- boilers and steam generators for steam and hot water
- kilns for cement, lime and brick industry
- furnaces, including blast furnaces, for various metallurgical processes and other industrial applications

Boilers can be operated by direct coal firing in different forms:

- pulverized coal burners, applicable for large boilers
- lump firing on grates
- coal-oil suspension burners
- atmospheric fluidized bed firing

For all boilers, except fluidized bed firing, the sulfur and ash content creates environmental problems, and need additional (to the gas/oil case) and expensive measures. In the case of gas, no constraints exist on the part of the users for most types of gas available. Constraints may exist as far as infrastructure (pipelines, storage, etc.) is concerned. In the future, the supply of various types of gas from non-conventional sources could be made available, e.g. biogas, through coal gasification, hydrogen, etc. In addition to the heat application, gas can also be used as replacement for oil and electricity in mechanical drive applications, including gas driven heat pumps for energy cascading.

Application of electricity for oil substitution can be grouped in two major categories:

a) Heating, which can be done at various temperature levels and for different materials by resistance, induction, arc and plasma heating and other methods.

b) Mechanical drive replacing combustion engines, steam turbines, gas turbines or steam engines; furthermore, by means of electric motor heat pumps, process heat can be upgraded and waste heat or environmental energy can be made available for a number of industrial processes.

Table 10: Applicable substitution technologies for important industrial sectors.

	Iron & steel	Cement & building material	Chemical	Paper & paper products	Engineering (machinery)
a) Direct Technologies					
Coal:					
Boilers, pulverized coal	+	-	+	+	S
Boilers, grates	+	-	+	+	+
Boilers, fluidized bed	+	+	+	+	+
Kilns	-	+	+	-	-
Furnaces	+	-	+	-	+
Blast furnaces	+	-	-	-	-
Coal-oil-suspension	S	S	S	S	S
Natural gas:					
Gas firing	+	+	+	+	+
Gas engine heat pump	-	-	+	+	-
Electricity:					
Resistance heating	+	-	+	-	+
Induction "	+	-	+	-	+
Arc "	+	-	-	-	-
Heat pumps "	+	+	+	+	+
Drives	+	+	+	+	+
Biomass and industrial waste	-	+	+	+	+
Municipal waste	-	+	-	-	-
District heat	-	+	+	+	+
Nuclear:					
Power	+	+	+	+	+
Low temp. heat (+ power)	-	-	S	+	+
High temp. heat (+ power)	S	-	-	-	-
Geothermal steam	-	-	S	S	S
b) Indirect Technologies					
Electricity generation	+	+	+	+	+
Coal gasification	-	+	+	+	+
c) Non-energetic Use					
Natural gas chemistry	-	-	+	-	-
Coal chemistry	-	-	+	-	-
Biomass chemistry	-	-	+	-	-

Note: + ... Generally applicable
 - ... Generally not applicable
 S ... In special cases

5. Conclusions

In spite of the recent trends towards diversification of the energy sources used by industry in the developing countries, the following problems remain:

- industries in most of the countries are still very dependent on oil for their energy supplies;
- insufficient development of electricity supply is hampering introduction of up-to-date industrial production technologies.

At present the most energy intensive industrial sectors in the developing countries are: non-metallic minerals, pulp and paper products, iron and steel, textiles, chemical industry, and food processing.

For purposes of energy analysis one can concentrate on the main existing or prospective technologies for each of those sectors. In most of the cases, the energy intensive parts of the production chain can be identified.

While at the final energy level (e.g. purchased electricity, oil products, gas, etc.), one can explore the trends in energy diversification, the useful energy level (e.g. process heat, mechanical drive, electro-processes, etc.) reveals the potential for substitution of energy forms as well as for extensive exploitation of the quality of energy in performing a given production task (e.g. through energy cascading, waste heat utilization etc.).

From the present structure of end-use energy distribution in developed countries, one can conclude that industrial energy is used mostly in the form of heat, e.g. process steam, direct heat, etc., followed by electric uses, and by feedstocks for chemical industry. However, any analysis of national industrial energy requirements, performed on a technological basis, with a view either to investigate energy substitution possibilities or to discern areas where inducing change may be possible, requires a detailed breakdown and scrutiny of the pattern of energy use, based either on energy audits or on externally supplied information about the available technological options.

The energy aspects of selected processes can be summarized as follows:

(a) Cement industry. The stage characterized by the highest energy consumption in the production process (over 90 per cent) is the clinker production step. Gas, oil products and a broad quality spectrum of coals are the alternative fuels for clinker production;

(b) Glass industry. The melting process consumes about 70 per cent of the total energy in the form of direct heat. Energy alternatives include gas, oil, electric and different modes for coal utilization. Several new energy efficient processes are at the pilot stage. Within the industry, a modest potential for heat recovery and application of solar devices exists;

(c) Iron and steel production. Three main production routes have been identified: blast furnace (BF) with oxygen converter (OC), electric arc furnace (EAF) for scrap processing, direct reduction (DR) and EAF. For each of these routes there exists a set of specific options for fuel substitution, utilization of product gases and waste heat recovery, which should be subject to detailed consideration and optimization;

(d) Textiles. Electricity is used mostly for motive power and specific uses, e.g. air conditioning, lighting, etc. A broad set of fuels could be burnt to supply process heat. A potential for energy cascading, cogeneration and waste heat reclamation as well as for solar energy utilization exists. Propane and methane are alternative fuels for direct heating;

(e) Aluminum. Process heat covers most of the requirements for refining aluminum ore into alumina. At this stage, fuel substitution and heat recovery potential exists. Electricity is the main energy input for the smelting process, transforming alumina to aluminum. Several energy saving options are feasible at this stage. The new Alcoa Chloride process reduces the energy requirements of the process;

(f) Paper and allied products. The technological cycle for an integrated pulping and forming plant could be made energy self sufficient by exploring the potential for cogeneration, energy cascading and heat recovery;

(g) Chemicals. A spectrum of new routes, including biomass utilization, for energy input diversification are at present in the developmental stage. A well conceived optimization of energy supply options is imperative.

The study of the energy aspects of selected processes at the plant level is made with a view to identifying the energy substitution options within a given production cycle. An extension of the boundary of the system, to include considerations for energy management of several plants located in a joint industrial development area, can broaden the range of options available, allowing for increased level of cogeneration of heat and electricity as well as for exploring of the potential for synergetic co-siting of industrial facilities.

6. Recommendations

6.1 To provide the basis for a reliable and resilient energy utilization system, efforts should be directed towards reducing the developing countries' dependence on high cost fuels. This can be achieved through:

- (i) Substitution of lower grade energy (e.g. cogeneration of steam and electricity by means of low quality coal) for higher grade (e.g. utilization of oil for water heating);
- (ii) Utilization of indigenous energy resources to replace imported fuels;
- (iii) Conservation of energy in the industrial sectors.

6.2 To achieve this, it is necessary to conduct a detailed assessment of the pattern, quality and quantity of industrial energy utilization, preferably in end-use terms, for the major energy consuming sectors of industry and to formulate respective energy policy.

6.3 This assessment should be conducted on the basis of:

- (a) A review of national overall and sectoral energy utilization patterns, derived from energy audits and surveys of energy utilizing enterprises, processes, and equipment;
- (b) A thorough inventory of indigenous energy resources and their present use;
- (c) The information basis for this assessment should be further strengthened by drawing on the appropriate reported experience in developed and developing countries;
- (d) A common methodology for industrial energy use assessment for developing countries could be attempted.

6.4 The energy policy measures formulated on the basis of this assessment should be supported by strengthening the respective institutional infrastructure in individual countries (especially engineering, training, and international co-operation).

REFERENCES

1. R.K. Cattell, Structuring industrial energy use: A UK case study, Energy Economist, October 1982.
2. UNIDO, World Industry 1980, ID/269.
3. UNIDO's Sectoral Studies Branch, Energy and Industrialization of Developing Countries Some Overall and Sectoral Considerations, UNIDO/IS, 1983.
4. UN, Report of the Technical Energy Group: The Economics of, the Potential for, Energy Conservation and Substitution, ACC Task Force Meeting on Long Term Development Objectives, 1983, New York.
5. N. Jr. Dean, Energy Efficiency in Industry, Ballinger Publ. Co., 1980.
6. T. Balabanov, Information Basis for Industrial Energy Management and Conservation: Analysis for the Developing Countries. Paper presented at the Meeting on Energy Management held in Sao Paulo, Brazil, 14-17 October 1982, UNIDO/OLADE.
7. P.V. Gilli and all., Industrial Sector Study of Oil Substitution, World Energy Conference, International Executive Council, Meeting 27 September 1981, Cancun, Mexico.
8. A. Bonomi and all., Estimates of the Specific Energy Consumption in Basic Industrial Processes with Respect to the First and Second Thermodynamic Principles, Commission of the European Communities, EUR 6752 EN, 1980.
9. World Energy Conference, Oil Substitution Task Force, Report of the Study Group on Developing Countries, August 1982.
10. The joint UNDP/World Bank Energy Sector Assessment Programme and Energy Sector Management Programme, a progress report, November 1982.
11. J. Astier, The Role of Energy in the Selection of Iron and Steelmaking Routes, February 1980.
12. J. Astier, Techno-economic Potentialities of Hydrogen Utilization for Steel Production, January 1980.
13. UN Statistical Yearbook, 1976, New York, and B. Kravis and all, Real GDP and per capital from more than one Hundred Countries, Economic Journal, Vol.88, 1978.
14. Industrial Energy Use Data Book, Oak Ridge Associated Universities, 1980.
15. M.S. Ar, Energy Conservation in Industry, Industrial Development Bank of Turkey, Istanbul, 1981.
16. R.J. deLuca and all., Energy Planning for Developing Countries: A Study of Bangladesh, The Johns Hopkins University Press, Baltimore, 1981.
17. J. Jankowski, Private communication.

