Chapter 4

Energy Services: Industry and Agriculture

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Contents

Box

Chapter 4

Energy Services: Industry and Agriculture

INTRODUCTION AND SUMMARY

The industrial sector is growing rapidly in many developing countries and is a key element in their drive for economic development and modernization. Between 1980 and 1989, annual growth of the industrial sector averaged 8.7 percent for the low income countries and 3.8 percent for the middle income countries. There was wide variation within these averages, however, ranging from a 5 percent or worse annual decline in production for Bolivia, Liberia, and Trinidad and Tobago to over 10 percent annual growth for China, South Korea, Indonesia, and several others.[1]

The industrial sector typically consumes 40 to 60 percent of total commercial fossil energy used in developing countries (see tables 4-1 to 4-3);[2] it also makes heavy use of traditional biomass fuels, often traded in commercial markets. For example, biomass fuels supply up to 40 percent of the industrial energy used in Indonesia, 28 percent in Thailand, 17 percent in Brazil, and similarly large fractions in many other countries.[3] Per capita industrial energy consumption in the developing world is 5 to 10 percent of the U.S. level (see table 4-2).

A significant portion of industrial energy is used technically inefficiently, with serious economic and environmental impacts. Improving overall performance of the industrial sector, not just the efficient use of energy, will be necessary if these countries are to compete in world markets and to provide a high standard of living for their citizens.

The industrial sector of developing countries includes a broad range of firms in size and sophistication. At one end of the spectrum are small traditional firms,[4] largely located in rural areas,[5] which use relatively energy inefficient and low productivity manufacturing technologies. These small manufacturing enterprises may, however, be operating efficiently in the broader economic context, given the available inputs of capital, labor, and materials.[6] High transport and marketing costs and small market size may prevent larger, more technically efficient firms from competing effectively with these traditional cottage industries. Over time, a few smaller companies grow into medium, and/or large ones as the transport infrastructure improves and incomes rise-increasing the size of markets and providing economies of scale that turn the advantage to larger firms,[7] At this end of the spectrum are large modern fins, often with multinational parent companies, that have globally competitive manufacturing capabilities.

Small Scale Industry

In many developing countries today, one-half to three-quarters of manufacturing employment is in small scale establishments; the remainder is divided more-or-less evenly between medium and large operations.[8] Small scale industry supplies one-fourth to one-half or more of manufacturing gross domestic product (GDP).[9] Much of the employment in the small traditional and primarily rural industries is based on seasonal labor available during the nonagriculturally active times of year; typically a fourth to a third of rural nonfarm employment is for

[1] World Bank, *World Development Report, 1990 (New* York, NY: Oxford University Press, 1990), pp. 180-181.

[2] Jayant Sathaye, Andre Ghirardi, and Lee Schipper, ''Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," *Annual Review of Energy*, vol. 12, 1987, pp. 253-281, table 5.

[3] Joy Dunkerley et al., *Energy Strategies for Developing Countries* (Baltimore, MD: Johns Hopkins University Press, 1981), p. 265.

[4] A variety of definitions and terms are used for small scale industry, including: household, cottage, micro, tiny, *small*, and others. Some Of these terms are used with distinct meanings according to the number employed, the location of the enterprise, and its assets. See Carl Liedholm and Donald Mead, "Small Scale Industries in Developing Countries: Empirical Evidence and Policy Implications, " Michigan State University International Development Paper No. 9, Department of Agricultural Economics, East Lansing, Michigan, 1987.

[5] Here, rural means localities with 20,000 people or less. See Carl Liedholm and Donald Mead, Ibid.

[6] This is based on a *social* benefit-cost analysis rather than total factor productivity. Ibid. See p. 68, ff.

[7] Dennis Anderson, ''Small Industry in Developing Countries: Some Issues,' World Bank Staff Working Paper No. 518, 1982.

[8] Ibid. See tables 1 and 2.

[9] Carl Liedholm and Donald Mead, op. cit., footnote 4.

Table 4-I-Total Delivered Energy by Sector, in Selected Regions of the World, 1985 (exajoules)[a]

	Residential/commercial		Industry		Transport		Total		
Region	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Total energy
Africa	1.0	4.0	2.0	0.2	1.5	NA	4.4	4.1	8.5
Latin America[c]	2.3	2.6	4.1	0.8	3.8	NA	10.1	3.4	13.5
India and China	7.3	4.7	13.0	0.2	2.0	NA	22.2	4.8	27.1
Other Asia[d]	1.9	3.2	4.0	0.4	1.9	NA	7.8	3.6	11.3
Developing countries	12.5	14.5	23.1	1.6	9.2	NA	44.5	15.9	60.4
United States	16.8	NA	16.4	NA	18.6	NA	51.8	NA	51.8

NA = Not available or not applicable.

NOTES: This is delivered energy and does not include conversion losses from fuel to electricity, in refineries, etc. The residential and commercial sector also includes others (e.g., public services, etc.) that do not fit in industry or transport. Traditional fuels such as wood are included under commercial fuels for the United States.

[a]1 exajoule (10^{18} Joules) equals 0.9478 Quads. To convert to Quads, multiply the above values by 0.9478.

[b]These estimates of traditional fuels are lower than those generally observed in field studies. See references below.

[c]Olade estimates these values, left to right, as 1.79 EJ, 1.50 EJ; 4.81 EJ, 0.5 EJ; 3.94 EJ,—; 10.54 EJ, 2.0 EJ; 12.54 EJ (Gabriel Sanchez-Sierra, Executive Secretary, Organization LatinoAmerica de Energia, Quito, Ecuador, personal communication, July 15, 1991.)

[d]Does not include Japan.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries,* OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991) p. 49.

Table 4-2-Delivered Energy Per Capita by Sector in Selected Regions, 1985 (Includes traditional fuels, In gigajoules)

Region	Residential and Commercial	Industry	Transport	Total
Africa	11.8	5.2	3.5	20.5
Latin America	12.7	12.5	9.7	34.9
India and China	6.7	7.3	1.1	15.1
Other Asia	7.2	6.2	2.7	16.1
United States	69.8	68.5	77.5	215.8

NOTE: These estimates do not include conversion losses in the energy sector, and underestimate the quantity of traditional fuels used compared to that observed in field studies. In Latin America, an alternative set of estimates are, left to right, 8.2GJ, 13.3 GJ, 9.9 GJ, 31.4 GJ (Gabriel Sanchez-Sierra, Executive Secretary, Organization Latino America de Energia, Quito, Ecuador, personal communication, July 15, 1991.)

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy In* Developing *Countries,* OTA-E-466 (Washington, DC: U.S. Government Printing Office, January 1991).

Table 4-3-Per Capita Energy Use by Service in Selected Countries (gigajoules)

	Brazil	China	India	Kenya	Taiwan	Us.
Residential	6.2	11.7	5.5	16.9	8.9	64.9
cooking	5.3	8.5	5.0	16.4	4.7	3.5
lighting	0.3	0.4	0.5	0.5	0.7	NA
appliances	0.6	NA	0.05	NA	3.1	13.0”
Commercial	1.5	0.7	0.26	0.4	4.2	45.2
cooking	0.4	NA	0.13	0.24	1.9	NA
lighting	0.5	NA	0.05	0.16	0.8	7.2
appliances	0.6	NA	0.07	NA	1.5	NA
Industrial	19.4	13.8	4.1	4.8	39.2	94.1
process heat	17.5	10.2	2.7	NA	NA	55.8
motor drive	1.6	3.6	1.3	NA	NA	20.4
lighting	0.1	NA	0.05	NA	NA	NA
Transport	13.3	1.2	1.3	2.7	11.5	80.8
road	12.0	0.2	0.8	1.8	10.1	66.7
rail	0.2	0.7	0.4	0.2	0.1	2.0
air	0.7	NA	0.1	0.7	0.7	11.3
Agriculture	2.1	1.8	0.6	0.5	2.6	2.5
Total	43.4	27.0	11.7	25.6	67.7	288.0

NA = Not available or not applicable.

[a]This is the combined total for appliances and lighting.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy In Developing Countries,* OTA-E-486 (Washington, DC, U.S. Government Printing Office, January 1991).

Photo credit: Appropriate Technologies, International

Some small scale rural industries, such as pottery-making, are frequently owned or staffed by women.

manufacturing.[10] This is an important source of income and employment for the rural and poor urban sectors.[11] Small scale industry also provides important inputs into larger scale industries-particularly in Asia—and into other key sectors such as agriculture.

Traditional rural industries include: crop processing activities; beer brewing; textiles and garment production; carpentry, masonry, and other construction; leatherworking and shoemaking; brick and pottery production; blacksmithing; and many others. These activities are often divided along tribal, class, or family lines and skills are usually passed along through the equivalent of apprenticeships.

Small industry in developing countries does not, however, mean exclusive use of traditional fuels. Many small shops use electric welding equipment, for example, and others would follow suit if electricity were available. The provision of modern fuels and power, such as electricity, offers significant opportunities to improve the productivity and quality of small manufacturing operations. On the other hand, many shops that work on modern equipment, ranging from autos to electric motors, often use the most primitive means and fuels available to perform the work. Shops that rewind electric motors, for example, often simply burn the windings off in an open fire rather than in a temperature controlled oven. This has potentially serious impacts on the performance of the motor after it is rewound.[12]

A key concern of the commercial establishment is fuel supply reliability: this has often led establishments, particularly those further from urban centers, to prefer firewood over more modern fuels.[13] Establishments that use wood in large volumes may also realize cost savings over modern fuels such as kerosene and liquified petroleum gases (LPG), particularly when they are imported.

The energy efficiency of traditional industry can be low (see table 4-4). The introduction of modern engineering analysis, design, and technology—including modern diagnostic instrumentation and analysis tools—into the traditional sector offers significant opportunities for improving the efficiency of traditional industry and improving product quality while minimizing capital investment. There are numerous examples. Principles of engineering combustion and heat transfer have been used to improve the energy efficiency of traditional stoves used for brewing beer, heating water for dyeing cloth, or other process heat needs.[14] Modern downdraft kiln designs have been introduced in West Africa and other regions to improve the energy efficiency of firing traditional clay pots and other goods. At the same time, these kilns can substan-

[10] Dennis Anderson and Mark Leiserson, "Rural Nonfarm Employment in Developing countries," *Economic Development and Cultural Change 28, No. 2, 1980,* table A2, p. 245; cited in Donald W. Jones, Oak Ridge National Laboratory, "Energy Requirements for Rural Development" Report No. ORNL-6468, June 1988. Measurements of this employment are very sensitive to the timing of the survey, how employment is defined, and the responsiveness of those interviewed. Under-reporting of nonfarm household employment is common; in some African countries it is reportedly as high as 40%. Dennis Anderson, "Small Industry in Developing Countries: Some Issues," World Bank Staff Working Paper No. 518, 1982.

[11] "Rural Small-Scale Industries and Employment in Africa and Asia," Ed. Enyinna Chuta and S.V. Sethuraman, International Labor Office, Geneva, 1984; Harold Lubell and Charbel Zarour, "Resilience Amidst Crisis: The Informal Sector of Dakar," *International Labour Review,* vol. 129, No. 3, 1990, pp. 387-396.

[12] Samuel F. Baldwin and Emile Finlay, "Energy-Efficient Electric Motor Drive Systems: A Field Study of the Jamaican Sugar Industry," Center for Energy and Environmental Studies, Princeton University, Working Paper No. 94. February 1988. Note that the oven must be carefully temperature controlled as well if damage to the windings is to be avoided.

[13] M. Macauley, M. Naimuddin, P.C. Agarwal, and J. Dunkerley, "Fuelwood Use In Urban Areas: A Case Study of Raipur, India," *The Energy Journal,* vol. 10, No. 3, July 1989, pp. 157-180.

[14] Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, and Dissemination* (Arlington, VA and Princeton, NJ: Volunteers in Technical Assistance and Center for Energy and Environmental Studies, 1986).

Table 4-4-Efficiency of Fuel Use In Traditional (Developing Countries) and Modern (Industrial Countries) Commercial and Industrial Operations

Activity	Location	Estimated efficiency of traditional technology	Estimated efficiency of modern technology in U.S.
Cooking	West Africa	15-1970	50-60%
Beer brewing	Burkina Faso	15-17	79"
	Burkina Faso	0.3-0.7	
Tobacco drying	Tanzania	0.5	(36%)[b]
Tea drying	Tanzania	2.9	NA
Baking	Sudan	12-19	43
	India	16.0	NA
	Guatemala	3.0	NA
Fish smoking	Tanzania	2-3	NA
Brick firing	Sudan	8-16	6-11
	India	6.4	NA
	Uganda	5-1o	NA
Foundry work	Indonesia	3.0	40

NA = Not available or not applicable.
[a]These are two different measures of the energy efficiency of the process.
[b]A proposal for a high efficiency tobacco curing barn with this efficiency can be found in H. Kadete, "Energy Conservation in Tobacco Curing," *Energy*, vol. 14, No. 7, pp. 415-420, 1989.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

tially improve the quality of the firing and reduce losses due to breakage.[15] Air-to-air heat exchangers for traditional foundry processes—such as melting scrap aluminum to cast pots-could recuperate perhaps a hundred times as much waste heat as would be required to power the small hand- or electric-driven blower powering the heat exchanger.[16] A variety of technologies for both traditional and modern industry are listed in table 4-5.

Small firms often face substantial obstacles to improving the efficiency of their operations, including energy use. These include: inadequate access to credit; internal lack of technical and managerial skills; inadequate infrastructure-roads, water, electricity; poor access to raw materials; poor access to markets; and sometimes systematic opposition by larger, better established, and better politically connected formal industry. Some of these barriers are summarized for both small and large industry in table 4-6 and possible policy responses are listed in table 4-7.[17]

There are numerous technical opportunities for improving the efficiency of energy use in small scale industry in developing countries. Financial, technical, and managerial extension efforts will be needed to realize these opportunities, a difficult task given the highly dispersed, small scale, and informal nature of this sector.

Modern Industry

Energy use by the small scale sector, though significant in many developing countries today, is likely to decrease in the future as a percentage of total industrial energy use. Much of the growth in industrial energy use will instead be in large scale energy intensive materials, such as steel and cement, needed to develop a modern economy. Such industries will be the primary focus here.

[15]In West Africa, for example, these products have traditionally been freed on open bonfires with correspondingly large energy losses, high breakage rates and low quality.

[16]Assuming a fan efficiency of 40 percent; and including the energy losses in converting fuel to electricity or food to muscle drive. See: Samuel F. Baldwin, op. cit., footnote 14.

[17]See Carl Liedholm and Donald Mead, op. cit., footnote 4. Hubert Schmitz, "Growth Constraints on Small Scale Manufacturing in Developing Countries: A Critical Review," *World Development*, vol. 10, No. 6, pp. 429-450, 1982; Hernando de Soto, *The Other Path: The Invisible Revolution in the Third World* (New York, NY: Harper & Row, 1989); Robert N. Gwynne, *New Horizons? Third World Industrialization in an International Framework* (New York, NY: John Wiley & Sons, 1990); Dennis Anderson, op. cit., footnote 7; Harold Lubell and Charbel Zarour, op. cit., footnote 11; G. Norcliffe, D. Freeman, and N. Miles, "Rural Industrialisation in Kenya," Enyinna Chuta and S.V. Sethuraman (eds.), *Rural Small-Scale Industries in Africa and Asia* (Geneva: International Labour Organisation, 1984).

Table 4-5—Selected Energy Efficient Technologies for the Industrial Sector

Energy service	Technologies and remarks[a]
Traditional technologies	
	The application of modern technologies and techniques to traditional technologies is a key area. So-called appropriate technology, however, has generally failed to accomplish much due to the general lack of highly skilled scientists and engineers in the efforts, the excessive emphasis on using traditional or local materials, and other factors.
Motor driven systems	
	High efficiency motors, pumps, fans, etc., electronic adjustable speed drives, optimized pipe, duct, etc. dimensions. Standardized testing is needed to compare performance on a uniform basis. Motors, etc. must also be properly maintained: with proper lubrication, adjustments to gears, belts, etc., maintaining phase balance of input electric power, etc. Improved design tools for sizing and controlling equipment needed. Standard protocols needed to incorporate load management techniques into adjustable speed drive.
Efficient process heat systems	
	Using waste heat recovery systems, including heat exchangers and vapor recompression systems; steam system improvements, including increased insulation, steam traps, desuperheating plant steam as needed, and plugging leaks; monitoring heat exchanger fouling; maintaining and upgrading furnaces--adjusting burners and excess air, preheating air intake, etc.; insulating steam lines, furnaces, etc.; improved combustion controls; and many other technologies and techniques. Particularly important is scaling down these technologies for use in smaller scale developing-country plants; and selectively adapting these technologies for developing-country conditions--where labor is lower cost, but may be less well trained for handling advanced equipment.
Processes	
	High efficiency industrial processes are at all stages of development. Particular attention needs to be given to directing and adapting this research to developing-country needs, taking into account: the lower labor costs and the scarcity of capital; the less well developed infrastructure (i.e., the frequent voltage fluctuations); the lower availability of highly-skilled technical and managerial manpower; and in some cases, the relatively less reliable maintenance infrastructure (i.e., making particular types of automatic controls desirable where they can prevent damage due to irregular maintenance).
Cogeneration	
	High pressure steam turbines, engines, gas turbines. Improved cogeneration technologies coming available include steam injected gas turbines, and others.
Equipment testing procedures, standards, and diagnostic equipment	
	Regional test centers for establishing uniform standards and testing equipment to it could be established. Diagnostic equipment and procedures need to be adapted to developing-country conditions.
Efficient design rules and design software	
	Research, development, and field verification needed for design rules in sizing and controlling plant and equipment
Advanced materials	
	High performance materials can dramatically reduce the volume of energy-intensive materials required. Particularly important for developing countries are high performance structural materials such as cements, steel, and plastics.
Quality control and just-in-time inventory control	
	Reduce defects and rework, material handling, and inventory costs; and improve productivity.
Recycling	
	Well established in developing countries. Development work needed to recycle complex composite materials and systems, e.g., as electronic equipment.

[a]Technologies can be viewed as on a spectrum of: (C) Commercially available; (A) commercially available in industrial countries but needing Adaptation to the conditions of developing countries; (N) Near commercial development; and (R) requiring further Research and development. Since most technologies have variations at many points on this spectrum—e.g., compact fluorescents are available, may need further adaptation in developing countries in some cases, have improved phosphors or other advances near commercial development, and may have more fundamental advances under research--the status of these technologies—C,A,N,R—will not be discussed; instead, particular opportunities will be presented.

SOURCES: Office of Technology Assessment; K.E. Nelson, "Use These Ideas to Cut Waste," *Hydrocarbon Processing*, March 1990; Julio R. Gamba, David A. Caplin, and John J. Mulckhuyse, "industrial Energy Rationalization in Developing Countries," World Bank, Johns Hopkins University Press, Baltimore, MD, 1986; U.S. Department of Commerce, National Bureau of Standards Handbook 115, "Energy Conservation Program Guide for Industry and Commerce," September 1974.

Modern large scale industries in developing countries are modeled after their counterparts in industrialized countries but are often operated at significantly lower efficiencies.[18] A few energy intensive materials-steel, cement, chemicals (especially fertilizer), and paper—account for much of the energy used by industry (see tables 4-8 to 4-10 and figure 4-1) and the total energy used to produce these materials will increase rapidly as developing countries build their national infrastructures of roads, buildings, industry, and power. For example, steel production in developing countries increased at an

[18]Detailed reviews of energy conservation in industrial plants can be found in: Julio R. Gamba, David A. Caplin, and John J. Mulckhuyse, *Industrial Energy Rationalization in Developing Countries* (Baltimore, MD: Johns Hopkins University Press, 1986).

Table 4-6-Barriers to Investment in Energy Efficient Technologies

Technical

Availability

High efficiency technologies and their needed support infrastructure of skilled manpower and spare parts may not be locally available. Foreign exchange may not be available to purchase critical spare parts. For the residential and commercial sectors, in particular, high efficiency technologies need to be marketed in a complete package to allow "one stop" shopping.

Culture

Culture is rarely an impediment to the use of energy efficient technologies, although it is frequently cited as a problem in disseminating technologies in rural areas. In most cases, the technology itself is found to have significant technical shortcomings or is unable to meet the multiple uses desired.

Design rules

Conventional design rules often lead to excessive oversizing of equipment-raising capital cost and wasting energy.

Diagnostics

Technologies for measuring the efficiency of equipment, as in industrial energy audits, are often awkward and inaccurate. Some of them may require shutting down a production line or making intrusive measurements, such as cutting holes in pipes or ducts to make flow and pressure drop measurements.

Infrastructure

The available infrastructure within a developing country may not be able to adequately support a particular high efficiency technology. This might include an electric power system with frequent brownouts or blackouts that the high efficiency technology is unable to handle well; dirty fuels that clog injectors; or poor water quality for high performance boilers. The developing country may also lack a reliable spare parts supply system and trained manpower to ensure adequate maintenance. Finally, the existing infrastructure might impede the implementation of a more efficient technology system. An extensive road system and/or little land use planning, for example, might slow or stop the development of an efficient mass transport system.

Reliability

Innovative high efficiency equipment may not have a well proven history of reliability, particularly under developing-country renditions, as for other equipment.

Research, development, demonstration

Developing countries may lack the financial means and the technical manpower to do needed RD&D in energy efficient technologies, or to make the needed adaptations in existing energy efficient technologies in use in the industrial countries to meet the conditions-e. g., large fluctuations in power supply voltage and frequency-in developing countries. Technology development and adaptation are particularly needed in rural industry and other activities.

Scale

Energy efficient technologies developed in the industrial countries are often too large in scale to be applicable in developing countries, given their smaller markets and lower quality transport infrastructure.

Scorekeeping methods

Methods of "measuring" energy savings may not be sufficiently accurate yet for the purpose of paying utilities or energy service companies for the savings that they have achieved. This must be contrasted with the ease of measuring the power generated or used. It is a particularly important issue for utilities, which usually earn revenues solely on the basis of energy sold and so have little incentive to assist efficiency efforts.

Technical and managerial manpower

There is generally a shortage of skilled technical and managerial manpower in developing countries for installing, operating, and maintaining energy efficient equipment. This may not be a significant problem where turnkey equipment is used.

Financial and economic

Behavior

Users may waste energy, for example, by leaving lights on. In some cases, such seeming waste maybe done for important reasons. Bus drivers in developing countries often leave their engines on for long periods, at a significant cost in fuel, in order to avoid jumpstarting their vehicle if the starter is broken, or to prevent customers from thinking (if the engine is off) that their vehicle is broken and going to a competitor whose engine is running.

cost

The high initial cost of energy efficient equipment to the end user and the high effective discount rate used by the end user discourage investment.

Currency exchange rate

fluctuations in the currency exchange rate raises the financial risk to firms who import high efficiency equipment with foreign exchange denominated loans.

Dispersed energy savings

Energy-efficiency improvements are scattered throughout the industrial and other sectors and are difficult to identify and exploit. In contrast conventional energy supplies may be more expensive, but are readily and reliably identified and employed. This tends to give planners a supply side bias irrespective of the potential of efficiency Improvements.

Financial accounting and budgeting methods

Factory accounts for paying energy bills may be separated from accounts for capital investment in more efficient equipment. Budgets for more efficient equipment may be rationed, forcing energy efficiency improvements to compete with each other for scarce budgeted funds even though the return on investment in efficiency maybe much higher than the overall cost of capital to the firm.

International energy prices
Uncertainty of international energy prices, such as oil, raises risks that price drops will reverse the profitability of investments in efficiency.

Multiple needs
The multiple roles and needs served by an existing technology may not be adequately met by a new energy efficient technology. Draft animals, for example, can provide meat, milk, leather, and dung in addition to traction power. They also reproduce. Mechanical drive only provides traction.

Risk
Particularly in poor rural and urban areas, people are highly risk averse; they have to be if they are to survive the vagaries of drought and other disasters. That villagers are risk averse should not, however, be construed to mean that they are technology averse. A variety of technologies have been adopted very rapidly in poor rural and urban areas.

Seasonality
Rural life is dominated by the seasons, with sharp labor shortages during the agricultural season and serious underemployment during the rest of the year that rural industry can only partly support. Capital investment in efficient agricultural or rural industrial technologies is relatively more expensive as it must pay for itself during just the fraction of the year it is used.

Secondary interest
Energy efficiency is often of secondary interest to potential users. In industry, for example, efficiency must compete with other equipment parameter--quality and quantity of product; timeliness, reliability, and flexibility; etc.-as well as other factors of production when investment choices are made and when the scarce time of skilled manpower is allocated. These are aspects of overall corporate strategy to improve profitability and competitiveness.

Secondhand markets
Low efficiency equipment may be widely circulated in secondhand markets in developing equipments, either among industries within developing countries, or perhaps as gifts or hand-me-downs from industrial countries. Further, users who anticipate selling equipment into the second hand market after only a few years may neither realize energy savings over a long enough period to cover the cost premium of the more efficient equipment nor, if secondhand markets provide no premium for high efficiency equipment, gain advantage in its sale.

Subsidized energy prices
Energy prices in developing countries are often controlled at well below the long run marginal rest, reducing end user incentive to invest in more efficient equipment. Energy prices may be subsidized for reasons of social equity, support for strategic economic sectors, or others, and with frequent adverse results. On the other hand, however, the low cost of power results in substantial financial costs to the utilities, providing them a potential incentive to invest in more efficient equipment on behalf of the user.

Threshold level of energy and cost savings
Users may not find a moderate level of energy or cost savings, particularly if spread over many different pieces of equipment, sufficiently attractive to justify the investment of technical or managerial manpower needed to realize the savings.

Unstable and/or low energy prices
Oil prices, in particular, have been volatile in recent years. This poses the risk that investments in other energy supplies will become uneconomic if the price of oil drops.

Institutional

Bias
There is often a bias towards a small number of large projects, usually for energy supply, than for small projects, usually energy efficiency, due to administrative simplicity and to minimize transaction costs.

Disconnect between purchaser and user
In a rental or lease arrangement, the owner will avoid paying the higher capital cost of more efficient equipment while the rentor or lessor is stuck with the resulting higher energy bills. Similarly, women in some countries may not have a strong role in household purchase decisions and may not themselves earn a cash income for their labor, but must use inefficient appliances purchased for them.

Disconnect between user and utility
Even though the total system capital cost is generally lower for energy efficient equipment, it is the user who pays for the more efficient equipment but only recoups the investment over the equipment lifetime while the utility sees an immediate capital savings.

Information
Potential users of energy efficient equipment may lack information on the opportunities and savings.

Intellectual property rights
Energy efficient technologies may be patented and the royalties for use may add to the initial costs for the equipment.

Political instability
Political instability raises risks to those who would invest in more efficient equipment that would only payoff in the mid-to long-term.

Turnkey systems
Turnkey and other package systems are often directly adopted by commercial or industrial operations in developing countries. In many cases, however, the equipment within these systems is based on minimizing capital cost rather than minimizing lifecycle operating costs.

SOURCE: Office of Technology Assessment, 1992.

Table 4-7—Policy Options

Alternative financial arrangements

Currently, the capital costs of generation equipment are payed by the utility and the capital costs of end use equipment are payed by the end user. The high effective discount rate of the end user as well as this separation between utility and user (or for leased equipment, the separation between owner and user) leads to much lower levels of investment in end use equipment efficiency than is justified on the basis of either total system capital costs or lifecycle operating costs. Alternative financial arrangements to redress this "disconnect" might range from the end user choosing equipment according to the total lifecycle cost and paying this cost in monthly installments on the utility bill; to the end user paying a front-end depositor posting a bond to the utility to cover the lifecycle operating rests of the equipment, against which the utility would charge the capital cost of the equipment and the monthly electricity y bills. Either of these approaches would force the end user to directly face the total lifecycle costs of the equipment when purchasing it. See also Integrated Resource Planning.

Data collection

The range of opportunities for energy efficient equipment, end user preferences, and operating conditions are not well known in many countries. Data collection, including detailed field studies, would help guide policy decisions.

Demonstrations

Many potential users of energy efficient equipment or processes remain unaware of the potential savings or unconvinced of the reliability and practicability of these changes under local conditions. Demonstration programs can show the effectiveness of the equipment, pinpoint potential problems, and in so doing convince potential users of the benefits of these changes.

Design tools

Computer design tools can be developed, validated, demonstrated, and widely disseminated to potential users.

Direct installation

In some cases, particularly where the cost of energy is subsidized by State operated utilities or where peak loads are reduced, the direct installation of energy efficient equipment or processes at low-or no-cost by the utility can reduce costs for both the utility and the user.

Energy audits

Energy audits by a skilled team, either factory employees or from the outside-perhaps associated with an energy service Co.--can provide highly useful specific information on where energy can be saved. In new plants or in retrofits, submetering of equipment In order to maintain an ongoing record of energy use can also be a very useful means of monitoring performance.

Energy service companies

Energy service companies—third parties that focus primarily on energy efficiency improvements within a factory and are paid according to how much energy they save--can play a valuable role in implementing energy efficiency gains. They can bring great expertise and experience to bear on the problem, and as their goal is saving energy rather than maintaining production, they are able to devote greater effort and focus to conservation activities. On the other hand, industry employees are sometimes reluctant to work with ESCos, believing that they could implement efficiency activities equally well if they had the time; and worrying that any changes to process or related equipment by the ESCo could disrupt the production line. Generic forms of contracts for ESCo services to industry need to be developed in order to adequately protect both parties, and pilot programs with ESCos can demonstrate the potential savings by ESCos and their ability to avoid disruption to processes. Compensation for the work done by ESCos should be based on "measured" energy savings, not on the basis of listing the measures taken, irrespective of their effectiveness. Utility programs that provide for competitive bidding on energy savings risk paying t he end-user and ESCo twice, once for the energy saved and once for the lower utility bill. This problem can be minimized by appropriately sharing the costs and benefits.

Extension efforts

Extension efforts may be useful at several levels. The efficiency and productivity of traditional rural industries might be significantly increased in a cost-effective manner with the introduction of a limited set of modern technologies and management tools. To do this, however, is extremely difficult due to the small and scattered nature of traditional rural industries and the large extension effort needed to reach it. Large industry in developing countries has many of the same needs--technical, managerial, and financial assistance--but can be reached more readily.

Grants

See "Direct installation," above.

Information programs

Lack of awareness about the potential of energy efficient equipment can be countered through a variety of information programs, including distribution of relevant literature directly to the industries concerned; presentation of competitions and awards for energy efficiency improvements.

Integrated resource planning (IRP)

Currently, utilities base their investment budgets on a comparison of the costs of different sources of generating capacity--coal, oil, gas, hydro, etc.-and the supply option that has the lowest cost for its particular application is chosen. Integrated Resource Planning expands this "least cost" planning system to include end use efficiency as an alternative to supply expansion in providing energy services. If energy efficiency is shown to be the lowest cost way of providing energy services, then under IRP utilities would invest in energy efficiency rather than new generating capacity.

Labeling programs

The efficiency of equipment can be clearly listed by labels. This provides purchasers a means of comparing alternatives. Measuring the efficiency of equipment, however, needs to be done in conjunction with standardized test procedures, perhaps established and monitored by regional test centers, rather than relying on disparate and perhaps misleading manufacturer claims.

Loans or rebates

Loans or rebates from the utility to the purchaser of energy efficient equipment can lower the first cost barrier seen by the user, and if incorporated in the utility rate base, can also prove profitable for them. On the other hand, users that would have purchased efficient equipment anyway then effectively get the loan or rebate for free--the "free rider" problem. This reduces the effectiveness of the utility program by raising the cost per additional user involved. This problem can be minimized by restricting the loans or rebates to the highest efficiency equipment for which there is little market penetration.

Marketing programs
A variety of marketing tools might be used to increase awareness of energy efficient technologies and increase their attractiveness. These might include radio, TV, and newspaper ads, billboards, public demonstrations, product endorsements, and many others.

Pricing policies
Energy prices should reflect rests, an obviously highly politicized issue in many countries. Where prices are heavily subsidized, the introduction of energy efficient equipment might be done in conjunction with price rationalization in order to minimize the price shock to users. Prices alone, however, are often insufficient to ensure full utilization of cost effective energy efficient technologies. There are too many other market failures as discussed above. As evidence of this, even the United States has adopted efficiency standards for a variety of appliances.

Private power
Opportunities to cogenerate or otherwise produce private power have frequently not been taken advantage of because State-owned or controlled utilities have refused to purchase privately generated power at reasonable costs-many State electricity y boards simply refuse to take privately generated power; many States impose a sales tax on self-generated electricity; many states decrease the maximum power available to industries with onsite generation capabilities, and then are reluctant to provide back-up power when cogeneration systems are down. In other cases, well-intentioned self generation taxes intended to prevent use of inefficient generators by industry penalizes efficient regeneration. finally, power is subsidized in many areas, making it difficult for private power to compete. Changes in laws mandating utility purchase of private power-such as that established by the U.S. Public Utilities Regulatory Policy Act laws—at reasonable rates would allow many of these opportunities to be seized. This should include establishing generic contracts that provide adequate protection to all concerned parties but that can be readily developed and implemented.

Protocols for equipment interfaces
The use of power line carriers or other techniques of utility load management will require common equipment interfaces and signaling techniques.

Rate incentives
See "Loans or rebates."

R&D: equipment processes, design rules
Examples of R&D needs are listed in the text. R&D programs might be established at regional centers of excellence in developing countries, possibly in conjunction with sister research institutes in the industrial countries.

Regional test and R&D centers
Regional centers of excellence are needed to help gather a critical mass of highly skilled technical manpower at a single site. The technologies to be developed should focus on those amenable to mass production while maintaining quality control under field conditions. Researchers and field extension agents should, in many cases, make greater use of market mechanisms to guide technology development efforts and to ensure accountability y.

Scorekeeping: savings and validation
Technologies and software for "measuring" energy savings need to be further developed and their effectiveness validated under field conditions. This would be a particularly valuable activity at regional centers of excellence.

Secondhand markets-standards
Efficiency labels or standards might be set for secondhand equipment. This might be particularly valuable for such things as secondhand factories sold to developing countries.

Standards for equipment and process efficiency
Many industrial countries have chosen to largely accept the financial "disconnect" between the utility and the user. Instead of providing low-cost, easily available capital to the end user and at the same time incorporating the full lifecycle cost of the end use equipment in the initial purchase, many industrial countries are attempting to overcome the economic and energy inefficiency of this disconnect by specifying minimum efficiency standards for appliances, buildings (residential and commercial), and, in some cases, industrial equipment.

Tax credits, accelerated depreciation
A variety of tax incentives-tax credits, accelerated depreciation, etc.—to stimulate investment in energy efficient or other desirable energy technologies might be employed.

Training programs
Training programs are needed in order to ensure adequate technical or managerial manpower. In addition, means of adequately compensating highly skilled and capable manpower are needed. Currently, skilled manpower-trained at government expense--is frequently attracted away from developing-country governmental organizations by the higher salaries of the private sector. Similarly, a more clear career path is needed for skilled technical and managerial manpower in energy efficiency just as utility operations now provide a career path for those interested in energy supply.

Utility demand and supply planning
Methodologies for integrated supply and demand least-cost planning have been developed by the industrial countries. These should now be adapted to the needs of developing countries and utility planners and regulators trained in their use.

Utility regulation
Utility regulations that inhibit the generation of private power (see above) or limit the role of the utility in implementing energy efficiency improvements on the supply or demand side need to be reevaluated. Means of rewarding utilities for energy saved as well as energy generated need to reexplored (see also scorekeeping). This might include incorporation of energy-efficient equipment into the utility ratebase.

SOURCE: Office of Technology Assessment, 1992.

Table 4-8—Energy Consumption in Industry, China, 1980

Sector	Final energy use: Exajoules	Percent
Basic metals (iron and steel)	2.38	25.7
Chemicals (fertilizer)	2.23	24.1
Building materials (cement, brick, tile)	1.44	15.6
Pulp and paper	0.25	2.7
Machine building	0.82	8.8
Textiles	0.64	6.9
Food, beverages, tobacco	0.38	4.1
Other	1.12	12.1
Total	9.26	100.0

SOURCE: *China: The Energy Sector,* World Bank Country Study, Washington, DC, 1985.

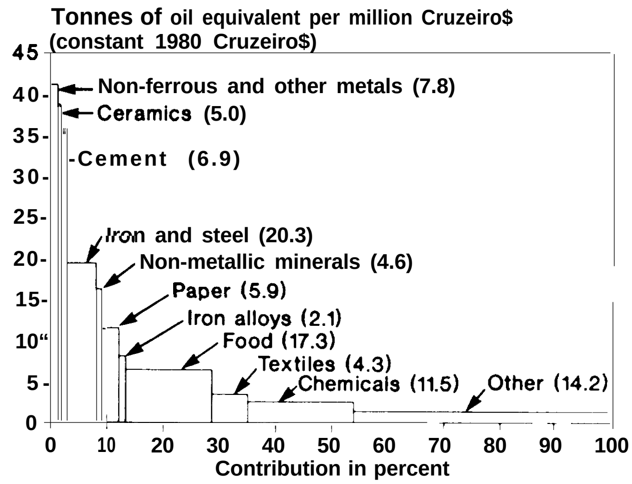
Table 4-9-Energy Consumption in industry, India, 1985/86

Sector	Coal PJ[a]	Oil PJ	Electricity[b] PJ	Total PJ
Paper	26.0	NA	4.1	30.1
Chemicals[c]	5.3	87.2	21.9	114,4
Cement	106.0	5.7	6.1	117.8
Primary metals	232.0	19.3	25.2	276.5
Textiles	23.6	22.1	13.2	58.9
Food	NA	12.2	2.8	15.0
Subtotal	393.0	147.0	73.0	613.0
Total industry	683.0	207.0	194.0	1,084.0

Coal-derived and natural gas not included.
aOne Petajoule (PJ) = 1 million Gigagoules (GJ) = 10^{15} Joules.
bElectricity is given in units of primary energy, converted from delivered kWh at 33 percent conversion efficiency fuel to electricity and 85 percent transmission & distribution efficiency, for overall efficiency of 28 percent.
cIncludes plastics, rubber, petrochemicals, fertilizer, paint, other, etc.
SOURCE: Ashok Desai, "Energy, Technology and Environment in India," contractor report to the Office of Technology

overall average rate of 7.3 percent between 1974 and 1982—significantly faster than the 5 percent rate of overall gross national product (GNP) growth.[19] At higher incomes, however, consumption of steel levels off as the market saturates (see figure 4-2). A similar trend has been found for a wide variety of materials.[20] A more detailed analysis has shown that

Figure 4-l-Final Energy Intensity Versus Manufacturing Value Added for Brazilian Manufacturing Industries in 1980



The number displayed for each bar is the sector's contribution to total final energy use in Brazilian manufacturing, in percent.

SOURCE: Jose Goldemberg et al., *Energy for Development* (Washington, DC: World Resources Institute, 1987).

at about U.S.$2,000 per capita GDP, both the production and the consumption of energy intensive materials largely saturates-the elasticity of production and consumption with GDP is near zero.[21] This point of saturation is, however, still a long way off for most developing countries.

Although consumer goods such as electric lights, refrigerators, televisions, and automobiles are less energy intensive to assemble than basic materials, large amounts of energy are nevertheless used in their manufacture. Most of this energy is for low temperature process heat and electricity to power motors driving pumps, fans, compressors, conveyors, and machine tools .22 The consumption of consumer goods is also increasing rapidly in developing countries, aided by their declining real cost

19Maurice Y. Meunier and Oscar de Bruyn Kops, World Bank, "Energy Efficiency in the Steel Industry with Emphasis on Developing Countries,' World Bank Technical Paper No. 22, 1984; and World Bank, *World Development Report 1990* (New York, NY: Oxford University Press, 1990), indicator tables 1 and 26. Note that steel production however, is concentrated in a few countries.

20Robert H. Williams, Eric D. Larson, and Marc H. Ross, "Materials, Affluence, and Industrial Energy Use,' *Annual Review of Energy,* vol. 12,1987, pp. 99-144. Simply put, there is a limit to the number of steel/cement intensive cars, refrigerators, buildings, roads, bridges, pipelines, etc. that a person needs. Eventually, consumption levels tend to plateau at replacement levels. When these wants for basic materials arfulfilled, people tend to spend incremental income on higher value-added materials-such as those with a high-quality finish—or on less material intensive but higher value added consumer goods. It is important to recognize these trends so as to not overestimate future demands for these energy-intensive materials.

21Alan M. Strout, "Ene~-btensive Materials, " Ashok V. Desai (cd.), *Patterns of Energy Use in Developing Countries* (New Delhi, India: Wiley Eastern Limited, 1990), pp. 106-107.

22The transition from an economy focussed on heavy industry producing energy intensive materials such as steel and cement to an economy that concentrates on the manufacture of consumer goods can have a profound impact on the overall energy intensity of the economy.

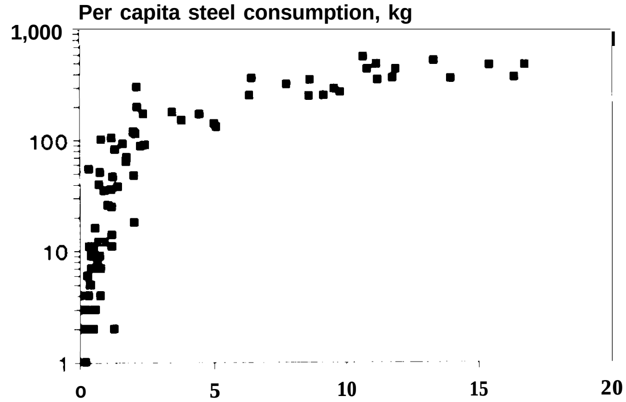
Table 4-10-Per Capita Primary Industrial Energy Use in The United States

Industry	U. S., 1980s Fuel (GJ/cap)	Electricity[a] (GJ/cap)
By subsector:		
Primary metals	10.1	6.1
Chemicals	11.1	6.3
Refining	23.5	1.9
Stone, clay, glass, cement	3.3	1.5
Pulp and paper	9.2	3.9
Food	3.4	2.0
Textiles	0.9	1.2
Machinery[b]	3.0	5.1
Subtotal	64.5	28.0
Other industry	2.5	3.1
By service:		
Motor drive	NA	21.7
Lighting and other	NA	2.9
Electrolytic	NA	4.4
Boilers	28.6	NA
Process heat	17.0	2.2
Feedstocks	21.4	NA

NA - Not available or very small.
[a]Electricity converted to primary fuel equivalent using a conversion factor of 0.33 for generation, transmission, and distribution combined.
[b]Includes the categories fabricated metal, machinery, electrical equipment, and transportation equipment.

SOURCE: Primary source of industrial and agricultural data is: OTA, Energy Efficiency in the Industrial Sector, forthcoming; data is for 1985.

Figure 4-2-Per Capita Steel Consumption Versus GNP for Various Countries



The saturation of the steel market at higher income levels as national infrastructures are developed is readily seen in linear or logarithmic plots. It is shown herein a semilog plot so as to better display both low-end and high-end data. Each data point represents a country.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries,* OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

with new materials and improved manufacturing techniques (see ch. 2).

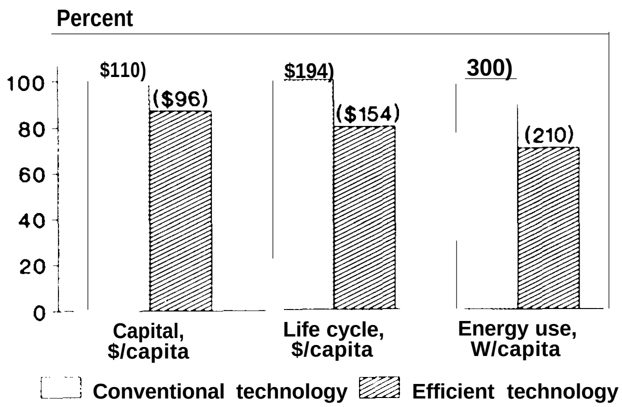
There are numerous opportunities to reduce the energy intensity of delivering industrial goods and their corresponding services (see table 4-5). Further, at least for electricity using technologies, these efficiency improvements generally lower both the total installed capital costs viewed from a societal perspective—factory investment plus upstream utility or other energy supply investment-as well as the life cycle operating cost for the user. These society wide financial advantages are shown in figures 4-3a and b together with the sharp shift in capital cost from the utility to the end user. Means of easing these capital costs to the user are needed if these high efficiency technologies are to be adopted and society to realize their financial and environmental advantages. These efficient technologies can also provide significant improvements in plant productivity, quality, and competitiveness.

Among the many opportunities for improving industrial energy efficiency, three are singled out here. It is important to view these opportunities, however, not as simple retrofits or equipment upgrades, but rather as one facet of the larger drive to modernize the industrial sector.

First, there are numerous opportunities to improve the energy efficiency of existing and new electric motor drive systems in industry. These include the use of motors designed for energy efficiency; the use of mechanical or electronic adjustable speed drives in order to match the speed of the motor to the load it is driving; improved pumps, fans, and other driven equipment; and improved design methods for properly sizing and interconnecting the many complicated components of a complete motor drive system. Motor drive will be a key focus here due to the importance of the electric sector in developing countries.

Second, there are a variety of ways in which specific manufacturing processes can be made more energy efficient. These are examined below for four industries-steel, cement, chemicals (fertilizer), and pulp and paper. These measures include housekeeping, retrofits of existing plants, and the establishment of state-of-the-art or advanced processes in new plants. Efficiency opportunities include the use of waste heat. Low temperature waste heat can be used in-plant to preheat materials; it can be used

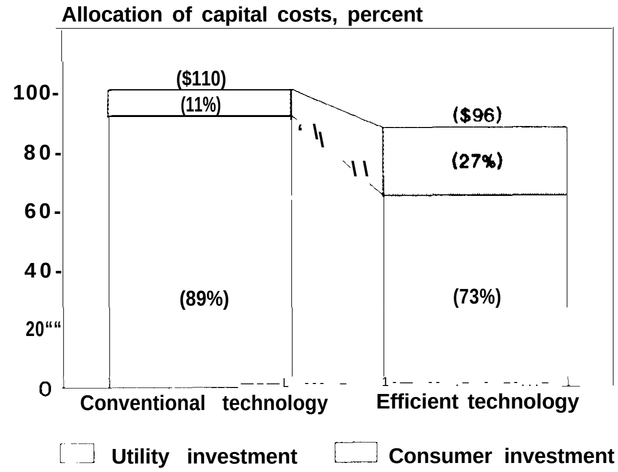
Figure 4-3A—Total Systemwide Capital and Life Cycle Operating Costs and Energy ‘Consumption for Conventional and High Efficiency Industrial Motor Drive Technologies



Over a wide range of conditions high efficiency technologies have a lower systemwide capital cost than the conventional technologies because the increased capital cost to consumers is more than offset by the decreased capital investment required in upstream electricity y generating plants. Life cycle operating costs are lower because the increased capital costs to the consumer are more than offset by the lower electricity costs to operate the equipment.

SOURCE: U.S. Congress, Office of Technology Assessment, 1992. See app. A for details of this calculation, including the assumptions and a sensitivity analysis.

Figure 4-3B—Allocation of Capital Costs for Conventional and High Efficiency Industrial Motor Drive Technologies



Although the high efficiency technologies have lower system wide capital casts, they dramatically shift the capital rests from the utility to the industrial or agricultural user. The high capital cost of efficient equipment to consumers is the reason why it is not more heavily invested in-even though it provides net savings to society overall and, indirectly, to the consumer. Means of reducing this initial capital cost barrier to the consumer are critical.

SOURCE: U.S. Congress, Office of Technology Assessment, 1992. See app. A for details of this calculation, including the assumptions and a sensitivity analysis.

outside of plant in neighboring industry or perhaps for district heating schemes in regions with cold weather such as northern China. High temperature waste heat can also be used in (or generated by) cogeneration systems. The focus here will be on the equipment and processes themselves.

Third, energy intensive materials can be used more effectively than at present. Smaller quantities of higher performance materials, such as high strength steel alloys, can often be substituted for larger quantities of lower performance materials. Materials can be more extensively recycled and products reused or remanufactured. Quality control as well as such techniques as near-net shape processing in producing basic materials or finished consumer goods can play an important role in saving energy by reducing the amount of scrap and reworking that is necessary.

Although the basic technologies remain the same, other factors—raw materials, capital, labor, technical and managerial manpower, political, trade regimes, and many others-vary dramatically between countries. These cases range from informal rural cottage industries, to protected nationalized industries with little external technical input, to subsidiaries of multinationals that have access to the best technologies available.[23] This wide range of conditions and capabilities requires a similarly wide range of policies in order to respond appropriately.

When considering various efficiency options, it is important to consider the time scales involved. At a sustained rate of growth in the industrial sector of 8 percent annually,[24] the manufacturing plant that exists now in a country will constitute less than half of the total manufacturing plant of the country in 10 years and less than one-fourth in 20 years. Housekeeping and retrofits of existing plants may be important over the short term for energy savings and for instilling a consciousness about the importance of energy savings. With such rapid growth, however,

[23]Depending on local conditions and corporate strategic plans, however, the corporation may not make use of the best technology it has available.

[24]The average annual growth rate of industry in the low income economies between 1965 and 1988 was about 8.8 percent. See: World Bank, *World Development Report 1990* (New York, NY: Oxford University Press, 1990), indicator table 2.

housekeeping and retrofits will play a much less significant role in saving energy over the longer term than ensuring that new investments are targeted towards high efficiency state-of-the-art plants or even the adoption of advanced manufacturing processes. The choice of targeting existing plant and equipment or new investments for energy efficiency will then depend on the complex tradeoffs of the potential gains versus the limited manpower and capital that can be invested.

On the other hand, the industrial sector is growing at a much slower rate in many other countries, particularly Africa and Latin America. In these areas, retrofits of existing plant and equipment must be emphasized-especially where capital constraints inhibit modernization generally .25

There are a variety of barriers to improving the energy efficiency in the industrial sector of developing countries. Some of these barriers as well as potential policy responses are summarized in tables 4-6 and 4-7.

Agriculture

Relatively little commercial energy is used directly in the agricultural sector, ranging from less than 1 percent of the national total in the United States to perhaps 5 to 8 percent of the national totals in developing countries such as Brazil, China, India, and Kenya. The developing countries, however, will need to increase energy intensive inputs-fertilizer, irrigation, improved crop varieties, and animal or mechanical traction-into agriculture if they are to keep up with their rapid population growth.[26] The agricultural sector is particularly important for the role it plays in improving the living standards of the rural poor.

The efficiency of many agricultural operations can be improved. These include improvements in pumping systems, mechanical traction, and in the production and application of chemicals such as fertilizers (discussed under industry). There are also many opportunities for decentralized power production through the use of renewable (see ch. 6) or for improving or changing the task itself-such as using drip irrigation or even going to advanced agroforestry or other agricultural techniques. A considerable effort to provide extension services will be necessary, however, if these opportunities are to be realized by the highly dispersed agricultural sector.

MOTOR DRIVE SYSTEMS[27]

Traditional industry, agriculture, transport, and household activities rely primarily on human and animal muscle for mechanical power. When only muscle power is available, many hours can be spent on ‘‘enabling’ activities, such as hauling water or grinding grain, rather than on more directly economically productive activities. Productive industrial or agricultural activities themselves are sharply limited by the low efficiency and output of muscle power. If the productivity of people in developing countries is to be increased, modern motor drive technologies and supporting infrastructures must be made available at affordable costs. As these technologies are adopted, energy use--especially electricity-will increase rapidly.

The efficiency, convenience, and high degree of control of electric motors provide dramatic efficiency and productivity improvements in industry, agriculture, and other sectors.[28] This led to a rapid transition in the industrialized countries from water and steam powered drive to electric drive in the early 1900s (see figure 4-4); the electricity intensity of industry continues to increase today in industrialized as well as developing countries.

Electric motor drive today consumes an estimated 58 to 68 percent of the electricity used in the United States and even more in the industrial sector alone. Motor drive is similarly important in developing countries (see tables 4-11 to 4-14). Electric motors

[25] Gabriel Sanchez-Sierra, organization Latino Americana de Energia, personat communication, July 15, 1991.

[26] The increase in energy use will be somewhat less for integrated agroforestry or other advanced sustainable agricultural approaches.

[27] Principal sources for this section are: Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems, " Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use andNew Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989, pp. 2 1-58), used with permission; Samuel F. Baldwin, ' 'The Materials Revolution and Energy Efficient Electric Motor Drive Systems, " *Annual Review of Energy,* vol. 13, 1988, pp. 67-94, used with permission from the *Annual Review of Energy,* vol. 13, copyright 1988 by Annual Reviews, Inc.; and Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems, " Princeton University, Center for Energy and Environmental Studies, Working Papers No. 91, 92, 93, and 94, February 1988.

[28] Samuel F. Baldwin, ''The Materials Revolution and Energy Efficient Electric Motor Drive Systems, ' *Annual Review of Energy,* vol. 13, 1988, pp. 67-94; W.D. Devine, Jr., "Historical Perspective on Electrification in Manufacturing, " S. Schurr and S. Sonenblum (eds.), *Electricity Use: Productive Efficiency and Economic Growth* (Palo Alto, CA: Electric Power Research Institute, 1986).

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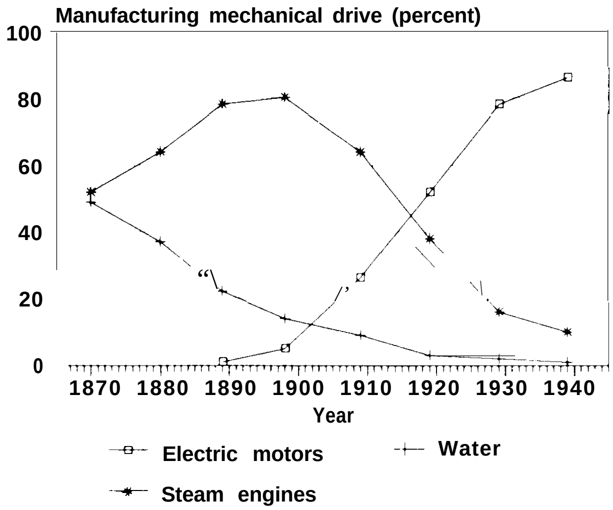
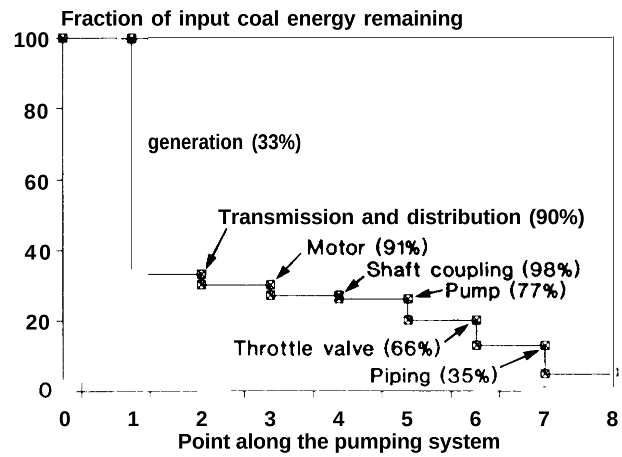
Figure 4-4--Percentage of Manufacturing Mechanical Drive From Water Power, Steam Engines, and Electric Motors by Year



SOURCE: Samuel F. Baldwin,' The Materials Revolution and Energy-Efficient Electric Motor Drive Systems," *Annual Review of Energy, vol. 13, 1988,* pp. 67-94.

Figure 4-5-Energy Losses in an Example Electric Motor-Driven Pumping System in the United States



This figure shows the useful energy remaining at each stage of a pumping system. The values in parentheses are the efficiencies of the particular device at each stage.

SOURCE: Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems," Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use andNew Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989) pp. 21-58.

are the workhorses of modern industrial society. They run home refrigerators; drive office air conditioners; power industries' pumps, fans, and compressors; and keep cities' water supplies flowing.

Significant efficiency improvements are possible in electric motors and the systems that they drive. These gains in energy efficiency usually reduce the total systemwide—including both the end user and the upstream utility--capital investment required as well as the life cycle operating costs for the user. These improvements will be discussed herein terms of the overall design and performance of motor drive systems and the performance of individual components.

Motor Drive System Design

Electric motor drive systems are often large and complex, involving numerous interacting components. The most common types of motor drive systems in industry include pumps, fans, compressors, conveyers, machine tools, and various rollers, crushers, and other direct-drive systems (see table 4-14). A pumping system is shown in figure 4-5 together with the efficiencies and net useful energy remaining at each point along the system.

Motor driven pumps, fans, and other system components are usually deliberately designed to be oversized, that is, to have excess capacity .29 These components are often oversized partly because it is difficult to predict system flow rates and friction factors accurately in advance, and to allow for the effect of the buildup of deposits on duct and pipe walls over time. Motors are oversized to handle starting electrical, mechanical, and thermal stresses, particularly with high-inertia loads; to provide a safety margin for the worst-case load over their lifetimes; and occasionally to handle plant expansion or perhaps to be widely interchangeable within the plant. In developing countries, oversizing motors is often important for preventing motor stall and possible burnout when the line voltage drops. More generally, these system components are oversized because the increased energy and capital costs to the end user are perceived to be less than the risk of equipment failure. In manufacturing, for example, average electricity costs in the United States are just 2.8 percent of the value-added;[30] the cost of motor

[29]On the other hand, pipes and ducts are often undersized to reduce capital costs.

[30]M. Ross, "Trends in the Use of Electricity in Manufacturing, " *IEEE Technology and Society,* vol. 5, No. 1, March 1986, pp. 18-22

Table 4-11—Industrial Electricity End Use in Brazil, 1984

Industry	Percent of total industrial electricity consumption	Fraction of subsector total for each end use (percent): Motor	Process heat	Direct heat	Electro-chemical	Light	Other
Nonferrous metals	20.9	32	1	35	32	1	NA
Iron and steel	12.4	1	NA	98	NA	1	NA
Chemicals	11.9	79	5	4	9	3	NA
Food and beverage	9.0	6	78	16	NA	1	3
Paper and pulp	6.5	87	8	2	NA	3	NA
Mining and pelletization	5.6	50	NA	49	NA	1	NA
Textiles	5.3	89	4	1	NA	5	1
Steel alloys	4.8	7	NA	92	NA	1	NA
Ceramics	3.9	65	NA	34	NA	1	NA
Cement	2.7	91	NA	6	NA	3	1
Other	17.0	76	2	16	NA	5	1
Total[a]	100.0	49	10	32	NA	2	NA

NA = Not applicable or not available.

[a]Total industrial electricity use was 10 terawatthours.

SOURCE: Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report, prepared for the Office of Technology Assessment, March 1990; published as *Efficient Electricity Use: A Development Strategy for Brazil* (Washington, DC: American Council for an Energy Efficient Economy, 1991).

Table 4-12—Projected Electricity Consumption in India by Sector and End Use, 1990 (percent of total national electricity use)

Sector	Total[a]	Industrial process: Motor drive	Industrial process: Electrolysis	Industrial process: Process heat	Lighting	Space conditioning: Cooling/ventilation	Space conditioning: Heating	Appliances: Refrigeration	Appliances: Other	Other miscellaneous
Residential	13.0	NA	NA	NA	4.2	3.5	NA	1.5	1.0	2.9
Urban	10.4	NA	NA	NA	2.9	2.9	NA	1.2	1.0	2.4
Rural	2.6	NA	NA	NA	1.3	0.5	NA	0.3	NA	0.5
Commercial	11.2	NA	NA	NA	4.8	1.6	1.5	0.4	0.8	2.1
Agriculture	18.4	18.4	NA	NA	NA	NA	NA	NA	NA	NA
industrial	54.8	33.4	10.8	5.5	5.1	NA	NA	NA	NA	NA
Primary metals[b]	17.2	6.4	6.9	3.0	0.9	NA	NA	NA	NA	NA
Chemicals	13.8	8.8	3.6	0.1	1.3	NA	NA	NA	NA	NA
Textiles	10.2	7.8	NA	0.4	2.1	NA	NA	NA	NA	NA
Coal, cement	6.8	5.8	NA	0.5	0.4	NA	NA	NA	NA	NA
Secondary metals[c]	3.4	1.5	0.2	1.4	0.2	NA	NA	NA	NA	NA
Paper	3.4	3.0	NA	0.1	0.3	NA	NA	NA	NA	NA
Railway traction	2.6	2.6	NA	NA	NA	NA	NA	NA	NA	NA
Motor drive	61.4	54.4	NA	NA	NA	5.1	NA	1.9	NA	NA

NA = Not available or not applicable.

[a]Total national consumption is projected to be 249.1 terawatthours in 1990.

[b]Aluminum, nonferrous, iron, and steel.

[c]Iron and steel.

SOURCE: Ahmad Faruqui, Greg Wilder, and Susan Shaffer, "Application of Demand-Side Management (DSM) To Relieve Electricity Shortages in India," contractor report prepared for the Office of Technology Assessment, April 1990.

Table 4-13—Electricity Consumption (GWh/year) by Service for 24 Industries in Karnataka, India (1984-85)

Industry	Motors	Process heat	Electrolysis	Lights cooling	Total	Share (percent)
Aluminum	43.4	0.0	343.0	1.57	387.9	22.4
Primary steel	61.6	233.6	0.0	4.83	300.0	17.3
Fertilizer,	206.9	0.0	0.0	1.17	208.1	12.0
Paper	193.4	0.0	0.0	1.05	194.5	11.2
Cement	185.6	0.0	0.0	1.18	186.8	10.8
Secondary steel	68.6	113.2	0.0	1.42	183.2	10.6
Ferro alloys ,	3.4	118.8	0.0	0.22	122.5	7.1
Caustic soda	13.3	0.0	95.6	0.48	109.4	6.3
Graphite	7.3	33.9	0.0	0.99	42.1	2.4
Total	783.6	499.5	438.6	12.90	1,735.0	100.0
Share (percent)	45.2	28.8	25.3	0.70	100.0	

SOURCE: AmulyaKumarN. Reddy, et al., "AD Development-Focussed End-Use-Oriented Energy Scenario for Karnataka: Part 2—Electricity:' Department of Management Studies, Indian Institute of Science, Bangalore, India.

Table 4-14—Disaggregation of Electricity Consumption (GWh/yr) by Motors for 24 Industries in Karnataka, India (1984-85)

Industry	Shaft power	Compressors	Pumps	Fans	Refining	Material handling	Agitating	Total	Shares (percent)
Aluminum	1.4	9.9	21.5	8.3	0.0	1.1	1.2	43.4	5.5
Primary steel	34.9	13.6	6.0	0.0	0.0	6.3	0.0	61.6	7,9
Fertilizer	2.3	164.2	39.0	0.0	0.0	1.4	0.0	206.9	26.4
Paper	48.5	4.7	66.5	9.2	53.2	3.5	7.7	193.4	24,7
Cement	97.6	13.7	10.5	58.3	0.0	5,6	0.0	185.6	23.7
Secondary steel	44.4	6.4	11.4	0.0	0.0	6.5	0.0	68.6	8.8
Ferro alloys	0.8	0.8	0.2	1.7	0.0	0.0	0.0	3.4	0.4
Caustic soda	0.4	3.0	6.6	2.5	0.0	0.3	0.4	13.3	1.7
Graphite	4,1	0.3	0.7	0.0	0.0	2.2	0.0	7.3	0.9

SOURCE: Amulya Kumar N. Reddy, et al., "A Development-Focussed End-Use-Oriented Energy Scenario for Karnataka: Part 2—Electricity," Department of Management Studies, Indian Institute of Science, Bangalore, India.

failure and unplanned shutdown of the entire process line can be a much more severe penalty .31

The intent of this design process is understandable and reasonable. Manufacturers, design engineers, and users all want to ensure that the system can meet the demands placed on it at every stage of the process. Although oversizing can provide direct safety margins for equipment, it can have unintended negative side effects. For example, when each successive element of a drive system is sized to handle the load presented by the previous component plus a safety margin, oversizing can quickly become excessive and require throttling valves on pumps or throttling vanes on fans to limit flow. In addition, many systems need variable outputs. Space heating and cooling, manufacturing, municipal water pumping, and most other motor drive loads vary with the time of day, the season, and even the health of the economy—such variations can be quite large.

Traditionally, throttling valves or vanes have been the principal means by which flow is controlled. This is, however, an extremely inefficient means of limiting flow. It is analogous to driving a car with the gas pedal floored, and then controlling the car's speed with the brake. Other systems of control, however, have generally been too expensive, less reliable, frequently difficult to control, or are themselves inefficient. Even simple approaches, such as turning a motor on and off to limit output—as with a home refrigerator-results in significant (if unseen) energy losses.

The direct and indirect energy losses due to such control strategies include part load operation, poor

[31] A.D. Little, Inc., *Energy Efficiency and Electric Motors*, U.S. Department of Commerce Report No. NTIS PB-259 129 (Springfield, VA: National Technical Information Service, 1976). "

power factor, throttling losses, excess duct or pipe friction, and pump or fan operation off the design point, among others. Standard engineering design rules, together with manufacturing safety margins, sometimes automatically lead to significant inefficiencies of this type, of which the user may be unaware. Industrial and commercial pumps, fans, and compressors, for example, have estimated average losses of 20 to 25 percent or more due to throttling or other inefficient control strategies alone.[32] The losses of complete systems can be much greater than this, as shown in figure 4-5. The largest single loss is in the process of electricity generation, but additional substantial losses take place at every stage throughout the system.

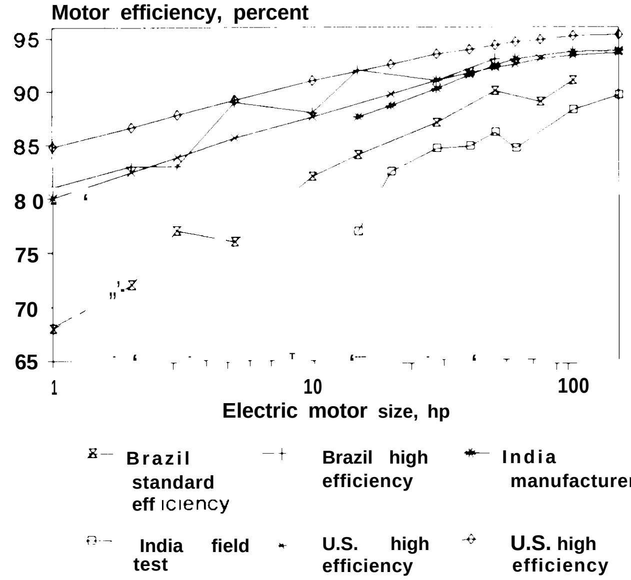
Motors

The efficiency of standard electric motors is often significantly lower in developing countries than in industrialized countries due to the use of lower quality materials in motor construction and improper techniques in maintenance, repair, and rewind (see figure 4-6).[33]

High efficiency motors are readily available in industrial countries and are sometimes available in developing countries, but in some cases cannot be used because of the poor quality of the electric power available. In Brazil, for example, the largest manufacturer of smaller motors exports more efficient models than those sold at home. These motors, comparable in efficiency to standard motors in the United States, often cannot be used in Brazil due to the excessive variation in the power line voltage. If the line voltage drops too much, the motor can stall and possibly burn out. Electronic Adjustable Speed Drives (ASDs) could buffer such voltage fluctuations, allowing use of the higher efficiency motor and providing significant energy savings (see below).

Typical costs for one class of standard and high efficiency electric motors in the industrial countries are shown in figure 4-7.[34] An industrial motor, however, can use electricity worth perhaps four times its capital cost annually .35 Thus, from the user perspective even the relatively small efficiency gains of high efficiency motors can quickly pay for their increased capital costs, particularly in a new installation or in replacing a damaged motor.

Figure 4-6-Efficiency of Electric Motors in the United States, Brazil, and India



SOURCE: U.S. Congress, Office of Technology Assessment, *Energy In Developing Countries,* OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

The benefits of improved motor efficiency are even more pronounced from the system perspective. In this case, the total capital costs of the system—including the upstream capital investment in utility generation, transmission, and distribution equipment along with the cost of the electric motor—decrease with improved motor efficiency (see figures 4-8a and b), Not only are total system capital costs reduced by using more efficient motors, but the substantial utility fuel use and operating costs are avoided. Total annual operating costs to users are also lower.

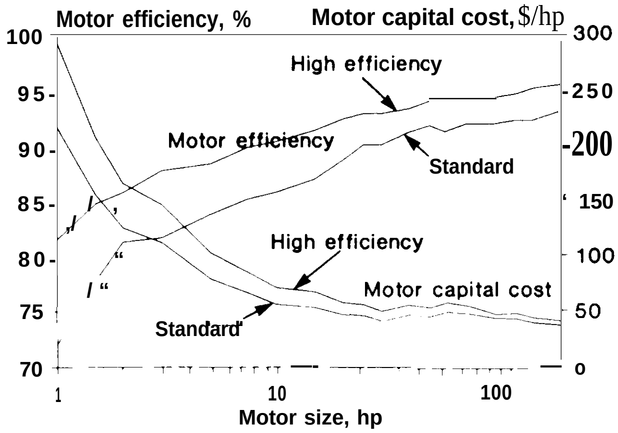
32 Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems," Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), op. cit., footnote 27; William J. McDonald and Herbert N. Hickok, "Energy Losses in Electrical Power Systems," *IEEE Transactions on Industry Applications,* vol. IA-21, No. 4, 1985, pp. 124-136.

33 Samuel F. Baldwin and Emile Finlay, op. cit., footnote 12. In particular, when motors are rewound they are sometimes simply put On an open fire to burn the insulation off the windings rather than putting them in temperature controlled ovens. This can damage the insulation between the core laminations and leads to greater losses.

34 The unit horsepower (h_p) is used here rather than kW in order to distinguish between kW of input electric power and hp of output shaft Power. One horsepower is equal to 0.7457 kW.

35 Operating 5,000 hours per year at 70-percent load, a 90-percent efficient motor annually *consumes* 2,900 kWh per hp. At $0.07/kWh this *costs* $200. *In* comparison, motors cost roughly $50/hp.

Figure 4-7—Efficiency and Cost of Standard and Energy Efficient Motors in an Industrial Country



This figure shows that for all sizes of motors, high efficiency models have a higher capital cost than standard models. This additional capital cost generally decreases as motor size increases. Note that these values are given per horsepower of motor capacity. Large motors will cost more in total, but less per unit capacity.

SOURCE: Marbek Resource Consultants, Ltd., "Energy Efficient Motors in Canada: Technologies, Market Factors and Penetration Rates," Energy Conservation Branch, Energy, Mines and Resources, Canada, November 1987. See app. A of this report for details.

Small but highly cost effective efficiency gains are also possible in many cases by increasing the size of the cables ruining to the motor and making other improvements in power system equipment.[36] For example, national standards for electrical cable sizes are often based on minimizing fire hazard rather than energy use. Larger cables are even safer because they have lower electrical resistance and generate less heat. These same characteristics can also enable larger cables to often quickly pay for themselves in reduced electricity costs to the user alone, not including the substantial upstream benefits of reduced system capital costs.[37] Other improvements in motors[38] and motor operating conditions[39] are possible that can provide small but highly cost effective energy savings. New technologies are also becoming available, such as high performance permanent magnet motors, that allow further improvements in efficiency.[w]

Plant engineers in many countries, however, may have a difficult time choosing between high efficiency motors offered on the market as measured efficiencies vary substantially according to the test standard[41] used (see table 4-15). In general, the Japanese test standard suggests higher efficiencies than the European standards, and the European standard gives higher values than the North American. Thus, a motor purchased from Japan could have a higher reported test efficiency but a lower actual efficiency than a similar motor purchased from the United States due to the difference in testing methodologies. This variation might correspondingly play a role in market competitiveness for different fins. It suggests a need for international efficiency testing protocols, probably best administered in regional test centers in both developed and developing countries.

Pumps and Fans[42]

Pumps and fans are, overall, the most common motor driven equipment.[43] In principle, equipment is chosen so that the optimal efficiency is matched to the operating conditions. In practice, there are numerous design complications due to oversizing,

36William J. McDonald and Herbert N. Hickok, "Energy Losses in Electrical Power Systems," *IEEE Transactions on Industry Applications,* vol. IA-21, No. 4, 1985, pp. 803-819.

37Amory B, Lovins et. al., *The State of the Art: Drivepower* (Snowmass, CO: Rocky Mountain Institute, April 1989).

38Of particular interest is minimizing core damage due to excessive temperatures when motors are rewound; and improving operating motor maintenance such as lubrication etc.

39Of particular interest may be improving the power factor, reducing voltage fluctuations on the line, balancing three-phase power, and controlling line harmonics,

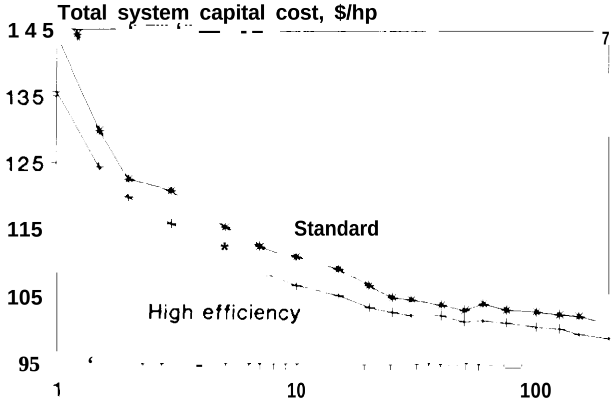
40Samuel F. Baldwin, ' 'Energy-Efficient Electric Motor Drive systems,' Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), op. cit., footnote 27; Amory B. Lovins et. al., *The State of the Art: Drivepower* (Snowmass, CO: Rocky Mountain Institute, April 1989).

41Note that the word "standard" here refers to the testing methodology used to measure motor performance. It does nOt mean a particular level of performance required by law or other codes.

42The use of the term "fans" here is intended to include industrial blowers.

43Pumps and fans are the primary focus here. The *consideration* for compressors are similar, with the exception that when using adjustable s@ drives the larger static pressure that compressors work against make it more difficult to optimally match the performance map of the compressor to the system load curve across a wide range of operating conditions. Conveyer systems for solid materials also use substantial amounts of electricity in industry, A brief review of potentialefficiency improvements in their design can be found in: William EBiles, "Solids Conveying," *Technology Menu for Efficient End-Use of Energy: Volume 1: Movement of Material* (Lund, Sweden: Environmental and Energy Systems Studies, Lund University Press, 1989).

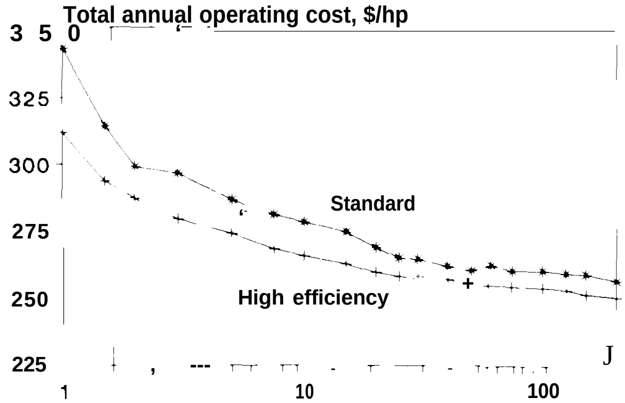
Figure 4-8A—Standard and High Efficiency Motor Capital Costs Including Motor and Upstream Utility Equipment To Power It



This figure shows that for all sizes of motors considered, total system capital costs are lower for high efficiency motors. Note that these values are given per horsepower of motor capacity. Large motors will cost more in total, but less per unit capacity.

SOURCE: U.S. Congress, Office of Technology Assessment, 1992. See app. A for details.

Figure 4-8B—Standard and High Efficiency Motor Operating Costs Including Both Annualized Motor Capital Investment and Annual Electricity Costs



This figure shows that for all sizes of motor considered, total annual operating costs are lower for high efficiency motors. Note that these values are given per horsepower of motor capacity.

SOURCE: U.S. Congress, Office of Technology Assessment, 1992. See app. A for details.

Table 4-1 5—Comparison of Efficiency Testing Standards for Motors

Standard	Motor size	Full-load efficiency (percent)			
		7.5 hp[a]		20 hp[a]	
CSA C390		80.3%.		86.9%	
NEMA MG-1		80.3		86.9	
IEC 34-2		82.3		89.4	
JEC-37		85.0		90.4	
	Motor size	5 hp[b]	10 hp[b]	20 hp[b]	75 hp[b]
IEEE 112B		86.2%	86.9%	90.4%	90.0%
IEC 34-2		88.3	89.2	91.4	92.7
JEC 37		88.8	89.7	91.9	93.1

NOTE: CSA is the Canadian Standards Association; NEMA is the National Electrical Manufacturers' Association (U.S.); IEC is the International Electrotechnical Commission (Europe); JEC is the Japanese Electrotechnical Commission; and IEEE is the Institute of Electrical and Electronic Engineers (U.S.).

SOURCES: [a]Steven Nadel et al., "Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities," (Washington, DC: American Council for an Energy Efficient Economy, 1991); [b] John C. Andreas, "Energy-Efficient Electric Motors," (New York, NY: Marcel Dekker, Inc., 1982).

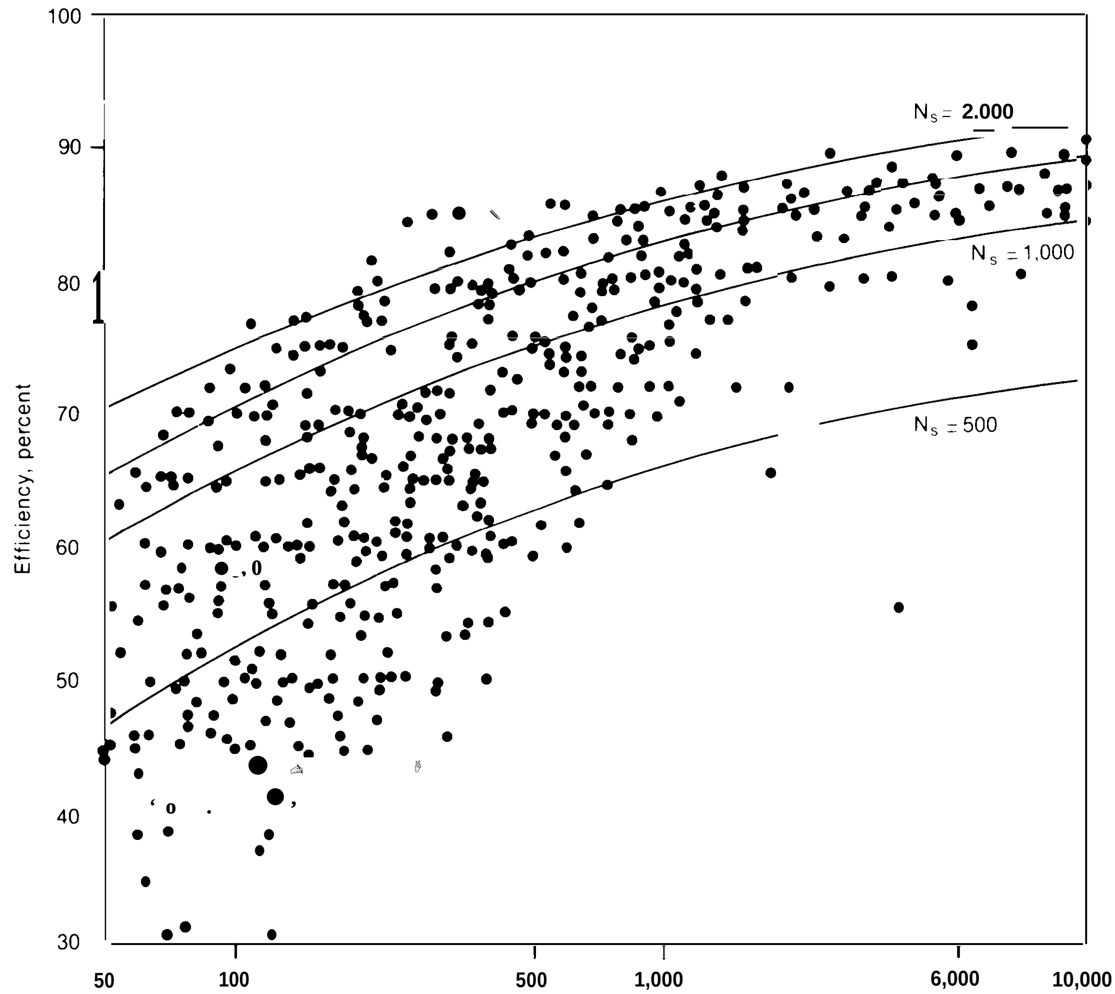
throttling, and other practices that move the system operating point away from the optimal efficiency.

Many pumps are also poorly designed and built, resulting in far lower efficiencies than technically and economically possible. Figure 4-9 shows the wide scatter in measured performance of new pumps in the United States. Factors that lower intrinsic pump efficiency include: excessive friction due to rough surfaces, poorly finished edges, and poorly shaped contours of the pump surfaces; interred leakage of fluid; and friction in the bearings and seals. Corresponding means of improving efficiencies include smoother and more carefully contoured internal surfaces; tighter tolerances;[44] and higher quality bearings. Further efficiency gains are often possible by operating the pump at a higher speed. Many of these efficiency improvements are possible at little cost.

Similar considerations apply to fans where large efficiency gains are likewise possible by choosing

[44] When pumping dirty water, etc. or mixed phase materials, larger tolerances may be preferable despite the efficiency penalty.

Figure 4-9—Actual New Pump Efficiencies at the Design Point, United States, 1970s



Note the wide scatter in efficiencies below what is expected in good design practice, as indicated by the solid lines for different pump speeds.

SOURCE: U.S. Department of Energy and Arthur D. Little, Inc., *Classification and Evacuation of Electric Motors and Pumps,* Report No. DOE-CS-0147 (Springfield, VA: National Technical Information Service, February 1980).

more efficient designs, operating them close to their design point, and by other means. Ranges for peak fan efficiencies are shown in table 4-16; many fans do not come close to these values. In some applications, of course, the highest efficiency designs cannot be applied .45 Of particular note is that backwardly curved fans are essentially interchangeable with forwardly curved fans, but are typically[10] to 20 percentage points more efficient at a roughly 15 percent cost premium. Fan and air handling efficiencies are particularly important in commercial buildings, where up to half of the electricity use

[45]Lower efficiency fans might be used, for example, to handle corrosive gases or gases with erosive particles such as those coming off a furnace.

Table 4-1 6-Estimated Maximum Total Efficiencies for Assorted Fan Designs

Type	Peak efficiency range (percent)
Centrifugal fans:	
Airfoil, backwardly-curved	79-83
Modified radial	72-79
Radial	69-75
Pressure blower	58-68
Forwardly curved	60-65
Axial fans:	
Vaneaxial	78-85
Tubeaxial	67-72
Propeller	45-50

SOURCE: J. Barrie Graham, "Fans," *Technology Menu For Efficient End-Use of Energy, Volume 1: Movement of Material,* Environmental and Energy Systems Studies, Lund University, Lund Sweden, 1989.

occurs in air handling systems for building heating, cooling, and ventilation.[46]

Many pumps and fans are also poorly maintained and efficiencies can decrease markedly over time due to wear. One study of 84 large pumping systems, primarily in pulp and paper mills in Sweden and Finland, found that wear alone had reduced average pump efficiencies by 14 percentage points compared to their original performance.[47]

Improvements in a pump or fan have a large upstream multiplicative impact due to the losses in transmission and distribution (typically 15 percent in developing countries), motors, couplings, and other equipment between the pump/fan and the utility (see figure 4-5), An example of the very large potential upstream capital and operating cost savings that are possible by improving pump or fan performance are shown in table 4-17. On an annualized basis, upstream utility capital cost savings are nearly 10 times greater than the incremental cost of the improved motor and pump/fan. Operating costs of the less efficient system increase this differential even more. Two factors give rise to this huge leverage: the multiplicative effect of the energy losses noted above; and the much greater capital cost per unit energy supply/demand for utility equipment than for the motor/pump system.

Despite these potential savings, users of pumps/fans have often not paid particular attention to pump or fan efficiency. There are many reasons for this: Pump/fan performance is difficult to measure in the field and requires special equipment and effort,[48] and it can require cutting holes in pipes or ducts as well as even shutting down a process line. Many users are unaware of the potential savings. Users are not directly exposed to and do not consider the utility investment requirements that result from their choice of pump or fan. In some cases, industrial users' electricity rates are subsidized (although industrial users often pay full price or even cross subsidize the residential, commercial, or agricultural sectors). Finally, industrial investment decisions are often shifted away from energy efficiency improvements due to tax structures; tariffs on imported high efficiency equipment (even though that may result in greater imports of expensive utility generating equipment); and internal financial accounting controls. For example, accounting procedures may use a limited capital improvements budget wherein projects compete against each other for a limited pool of funds rather than against an external market interest rate determined rate-of-return criteria.

In addition, many users, unaware of the large potential energy savings, justifiably place very high premiums on the proven reliability of a certain type of pump/fan and its manufacturer; on minimizing spare parts inventories and simplifying maintenance; and on timely delivery of spares. For example, users are often unwilling to switch to a different manufacturer to get a few percent higher efficiency pump/fan for a specific application when their regular manufacturer's offerings do not provide a high efficiency pump/fan in that flow and pressure range. Many pumps/fans are incorporated in other equipment by Original Equipment Manufacturers

[46] J. Barrie Graham, " Fans," *Technology Menu For Efficient End-Use of Energy, Volume 1: Movement of Material* (Lund, Sweden: Environmental and Energy Systems Studies, Lund University Press, 1989); "Fans: A Special Report,'' *Power,* September 1983; Scott L. Englander, "Ventilation Control for Energy Conservation: Digitally Controlled Terminal Boxes and Variable Speed Drives, " Princeton University, Center for Energy and Environmental Studies, Report No. 248, March 1990.

[47] Eric D. Larson and Lars J. Nilsson, "Electricity Use and Efficiency in Pumping and Air Handling Systems,' paper presented at ASHRAE Transactions, June 1991 ASHRAE Meeting, Indianapolis, IN.

[48] For example, t. measure pump efficiency requires that the motor power input to the pump and the pump power output (flow of liquid and Pressure drop) be measured. To measure the motor power input to the pump in the field requires the use of power meters and tachometers. To measure the flow and pressure drop across a pump requires flow meters and pressure gauges and is usually an invasive procedure. For more information, see: Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems, ' Princeton University, Center for Energy and Environmental Studies, Working Papers No. 91,92, 93, and 94, February 1988.

Table 4-17-Capital and Energy Savings With Improved Pumps

	Standard pump system			Efficient pump system		
	Efficiency percent	Power output kW	Annual capital cost dollars	Efficiency percent	Power output kW	Annual capital cost dollars
Generator	—	.			—	—
		17.4	—	—	15.6	—
T&D	85%	.	—	85%	—	
		14.8	$3,250	—	13.3	$2,936
Motor	90%	—		94%	—	
		13.3	$ 107	—	12.5	$121
Pump	7570	—	—	80%	—	
		10.0	$ 110		10.0	$132
Total capital			$3,467			$3,189
Investment in motor/pump						$ 36
Annual capital savings			—			$ 278
Annual electricity savings			—			$ 540

How to read this table: This table illustrates the impact of improved equipment efficiencies on capital expenditures for a hypothetical pumping system. In the standard pump case, the delivery of 10 kW in pumping power output requires a motor output of 13.3 kW, a transmission & distribution (T&D) system output to the motor of 14.8 kW, and a generator output of 17.4 kW due to the losses at each step of the system (efficiencies of 75%, 90%, and 85% respectively). The corresponding annual capital costs are $3,250 for generation plus T&D, $107 for the motor, and $110 for the pump. In the system with improved pump and motor efficiencies, to provide 10 kW in pumping power output, just 15.6 kW are needed at the generator busbar. The improved motor and pump have an annual capital cost $36 greater than in the standard case, but reduce the annual capital expenditure for generation and T&D equipment by $314, for a net capital savings of $278. Electricity (capital plus fuel) savings total $540 annually.

NOTES: This assumes a capital cost of $4,000/kW for delivered power from the generator through the T&D system as detailed in Appendix A at the back of this report. It assumes standard motors and pumps/fans cost $100/kW output, and efficient motors and pumps/fans cost 20 percent more. The pump is assumed to run 6000 hours per year corresponding to typical two shift operation at an industrial plant. Total capital costs are annualized using a 30-year 7-percent discount rate to get a capital recovery factor of 0.0806. The same 30 year lifetime and discount rate is assumed for the motor and a 15-year life is assumed for the pump (CRF=0.11). Note that this calculation assumes exact sizing of the motor and fan rather than sizing to the nearest available size. Finally, it assumes electricity costs $0.06/kWh corresponding to preferential industrial rates. The listed annual electricity savings include the annualized capital savings.

It has been estimated that for a 20-percent price premium on pumps, an average efficiency improvement of 10 percentage points is possible for pumps smaller than 5 hp (3.7 kW) decreasing to 2 percentage points for pumps larger than 125 hp (93 kW).[a] Similarly, backward-curved (blade) fans have been estimated to cost about 15 percent more than the equivalent forward-curved fans, but give a 10-20 percentage point improvement in efficiency—corresponding to savings of 2-4 times that listed above.[b]

[a]U.S. Department of Energy and Arthur D. Little, Inc, "Classification and Evaluation of Electric Motors and Pumps," DOE/CS-0147, 1980.

[b]Eric D. Larson and Lars J. Nilsson, "Electricity Use and Efficiency in Pumping and Air-Handling Systems," to be published in ASHRAE Transactions, presented at the June 1991 ASHRAE Meeting, Indianapolis, IN.

SOURCE: Office of Technology Assessment, 1992.

(OEMs) and sold as a package; lowest first cost, not energy efficiency, is usually the primary concern of an OEM.[49]

As for the case of electric motors, these considerations suggest the need for careful, standardized testing of new pump/fan efficiencies; ongoing monitoring of pump/fan performance in the field; wide dissemination of both new and field measured performance of pumps/fans; and finding a means of incorporating potential utility capital savings in the considerations of the industrial end user.

Adjustable Speed Drives

Adjustable speed drive (ASD) technology allows a significant change in system design and operation. In contrast to the conventional practice of oversizing systems, using constant-speed motors to drive them, and throttling excess flow with vanes or valves, ASDs and their associated sensors and controllers allow precise matching of motor speed to load. This can significantly improve overall system efficiencies both directly and indirectly. Further, this flexibility may allow design rules that lead to extreme oversizing to be relaxed, potentially reducing capital investment in some system components by the end user.

ASDs offer a number of other benefits as well. They often increase equipment lifetimes:

- by avoiding the back-pressures generated by conventional throttle valves or vanes used to limit the output of pumps or fans;

[49]U.S. Department of Energy and Arthur D. Little, Inc., "Classification and Evaluation of Electric Motors and Pumps,' Report No. DOE/CS-0147 (Springfield, VA: National Technical Information Service, 1980).

- by permitting constant lubrication of bearings—in contrast to equipment operated in an on-off mode;
- by allowing operation at reduced speeds; and
- by permitting slow, controlled starts to reduce electrical stresses on motors, transformers, and switchgear, and to reduce mechanical stresses on motors, gears, and associated equipment.

Other ASD advantages include:

- isolation of the motor from the power line, which can reduce problems caused by varying or unbalanced line voltage;
- a ''ride through' capability if there is a power failure for a few cycles;
- operation at higher speeds than the 60-Hz line frequency allows; and
- easy retrofits to existing equipment.

Finally, and perhaps most importantly:

- ASDs often provide better control over manufacturing processes or in other equipment than conventional systems can achieve, improving process and product quality.

This description may suggest that ASDs are hi-tech devices applicable only in advanced manufacturing plants in industrial countries. In fact, ASDs are likely to become ubiquitous and offer significant opportunities in developing countries--by buffering line voltage fluctuations, reducing systemwide capital costs, reducing user operating costs, reducing energy use, and improving the manufacturing process, among others.

Adjustable-speed drives are being successfully used in numerous applications today in OECD countries and their use could be extended to developing countries. In industry they are used in boiler fans in chemical plants, utility plants, packaging equipment, glass-blowing machines, cement factories, and many others. In commerce they are used in commercial refrigeration systems, heating, ventilation, and air conditioning (HVAC) systems for buildings, and other applications. In residences, they are used in air conditioning and heat pump systems.[50] Several hundred thousand ASDs have now been sold in the United States.

Individual case studies have documented energy savings of 30 to 50 percent in fan and boiler feedpumps, 20 to 25 percent in compressors, 30 to 35 percent in blowers and fans, 20 to 25 percent in pumps, 25 to 35 percent in central refrigeration systems, and 20 percent in air conditioning and heat pumps.[51] Of course, ASDs do not provide savings in constant-speed full load applications, so national energy savings will be less than might be calculated by assuming universal adoption at the above efficiencies.

The capital costs of ASDs have declined some 7 to 12 percent in real terms over the past 4 years[52] and are likely to continue slowly declining with improvements in ASD technology, manufacturing processes, and as further economies of scale and learning in manufacturing are achieved.[53] Figures 4-10a, b, and c show current capital costs for ASDs, and the corresponding total system capital costs (including those of the utility) and life cycle operating costs.[54] At the low end of the size scale (a fraction of a horsepower (hp)--not shown), the cost of mass produced ASDs used with residential heat

[50] Detailed listings of references for each of these cases are given in Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems,' Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), op. cit., footnote 27.

[51] Detailed listings of these case studies can be found in Baldwin, Ibid.

[52] Eric D. Larson and Lars J. Nilsson, "Elecrncity Use and Efficiency in Pumping and Air Handling Systems,' paper presented at ASHRAE Transactions, June 1991 ASHRAE Meeting, Indianapolis, IN.

[53] Costs will not decline as rapidl, as they have for other electronics technologies, however. For example, much of the dramatic decline in cost and performance increases in the computer industry are possible because individual transistors on integrated circuits can be scaled down in size with no loss of function (actually, there is a gain in performance as higher system operating speeds are then possible). Computer circuits handle information and there is no inherent lower limit on the amount of energy needed to carry a bit dinformation, at least down to inherent circuit noise. Incontrast, ASDs handle large amounts of power-up to thousands of kilowatts-in order to drive a motorTo handle these powers requires large quantities of very high quality electronic materials, primarily silicon, and the quantities of material required cannot be scaled down as they can for a computer circuit. This greatly slows the pace at which costs can be reduced. For smaller loads such as refrigerators and air conditioners, however, power mosfets may allow the entire ASD to be fabricated on a single chip. This would allow significant costreductions in this size range as fabrication yields improved.

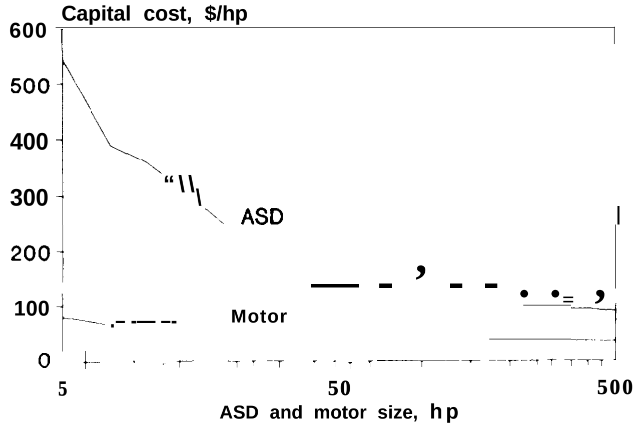
[54] Additional details on ASD capital costs can be found in: Power Electronics Applications Center, Directory Adjustable *Speed Drives*, second edition (Palo Alto, CA: Electric Power Research Institute, 1987); and Everett B. Turner and Charles LeMone, "Adjustable-Speed Drive Applications in the Oil and Gas Pipeline Industry, " *IEEE Transactions on Industry Applications,* vol. 25, No. 1, pp. 30-35, 1989. In large sizes, e.g., 750 hp and above, ASD capital costs can be less than $100/hp at the low-cost end; at sizes of 5,000 hp and above, ASD capital costs approach $50-60/hp at the low-cost end and $100/hp at the high-cost end.

pumps and other appliances is reportedly down to $25/hp ($33/kilowatt) .55

Systemwide financial considerations—including the cost of the ASD and the avoided utility capital investment-were recently applied in Canada. In that case, an ASD was chosen to drive a coal slurry pipeline rather than relying on a conventional throttling valve for control. The reason for this choice was simple. The cost to the company of the 3,500 hp (2.6 megawatts) ASD equipment and installation was Can$800,000; to raise the capacity of the local supply system to power the less efficient throttle controlled design would have cost the company Can$1,000,000 even including a capital cost sharing arrangement with the local utility and would have delayed the project 4 months. The company chose the ASD over the less efficient throttle valve to avoid those upstream costs and delays.[56]

ASDs will also be used increasingly in household and commercial refrigeration and air conditioning systems due to their efficiency and other advantages. By modifying the design of these ASDs and establishing standard protocols, direct implementation of load management techniques via power-line carriers or other means may then be possible at very low marginal costs. For example, circuitry to detect a power-line carrier signal and then to turn down or turn off a refrigerator or air conditioner could be incorporated directly into its ASD. Time-of-day electricity cost controls could be similarly implemented. Simple on-off load management techniques are already used in large scale systems in the United States and Europe. Southern California Edison, for example, has 100,000 air conditioners in a load management program networked via a VHF-FM radio system. Despite the high cost of establishing the system—approximately $120 per participating household just for the control devices, their installation, and marketing-benefits have been almost 4 times greater, Further, the program has been very

Figure 4-10A—Capital Costs for Electric Motors and ASDs Alone



This does not include utility investment nor additional engineering costs for designing and emplacing the ASD beyond those for the motor alone. These engineering rests can greatly increase the cost of an ASD system; with extensive experience, however, these additional engineering costs should be readily reducible. Note that these rests are given per horsepower of capacity. Large units will cost more in total, but less per unit capacity.

SOURCE: Capital costs for ASDs are from Steven Nadel et. al., *Energy Efficient Motor Systems: A Handbook on Technology, Programs, and Policy Opportunities* (Washington, DC: American Council for an Energy Efficient Economy, 1991).

well received; just 1.8 percent of the participants have withdrawn voluntarily. These techniques allow a substantial reduction in peak utility loads with corresponding savings.

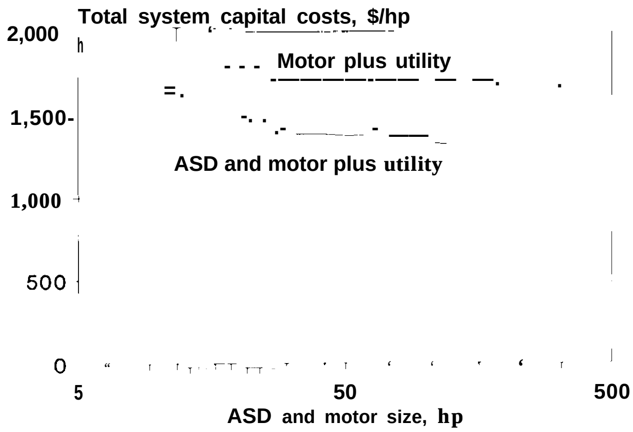
ASDs do have some drawbacks. In particular, ASDs can distort the shape of the normal voltage waveform in the power grid.[57] This distortion can reduce the efficiency of motors, transformers, and other equipment. It can also interfere with computers, communications, and other equipment. Techniques are available to control this problem and further work to lower the costs of control is ongoing. With proper design up front-as opposed to onsite remediation after installation-harmonic control is relatively low cost and straightforward. Many OECD countries have established legislation limiting the distortion allowable from ASDs and related devices

[55] Steve Greenberg et. al., *Technology Assessment: Adjustable-Speed Motors and Motor Drives (Residential and Commercial Sectors)* **(Berkeley, CA: Lawrence Berkeley Laboratory, 1988).**

[56] Frank **A.** Dewinter and Brian J. Kedrosky, **"The Application of a 3,500-hp Variable Frequency Drive for Pipeline Pump Control,** *IEEE Transactions on Industry Applications,* **vol.** *25, No. 6, 1989,* **pp. 1019-1024.**

[57] In more technical t.,n, ASDs are nonlinear electronic devices that can inject harmonics into the power line. Converters that use thyristors cause **line notching-a brief short circuit that sends the line voltage abruptly to zero at that point. Furthermore, the current drawn is closer to a square wave than a sine wave. Converters that use diode bridges draw current in a periodic pulse and also cause distortion of the line voltage. A six-step** inverter will **generate characteristic harmonics at** nK+/-1 = **5,7,11,13,17, . . . times the line frequency, each with maximum theoretical amplitudes equal to (l/harmonic) of the fundamental. Twelve-step** inverters can, **in principle, significantly reduce the generation of harmonics, but in practice system reactance and converter phase shifts somewhat reduce their advantage.**

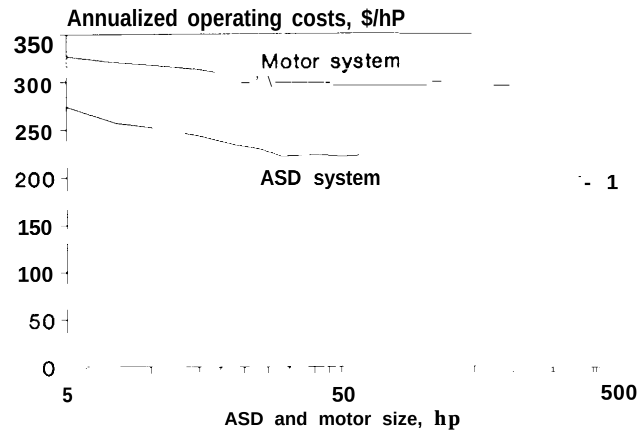
Figure 4-10B—System Capital Costs for a Motor (Plus Utility Investment to Power It) and for an ASD/Motor (Plus Utility) System



When upstream utility capital costs are included, the more efficient ASD/Motor system has lower capital costs than less efficient motors (plus utility) alone.

SOURCE: Office of Technology Assessment, 1992. See app. A for details.

Figure 4-10C—Annualized Operating Costs for Motor and ASD/Motor Systems



More efficient AS D/motor systems have lower annualized operating costs than less efficient motors alone.

SOURCE: Office of Technology Assessment, 1992. See app. A for details.

and much of this analysis should be readily transferable to developing countries.[58]

The total electricity savings possible by the use of ASDs is not yet well understood and more research is needed. Total savings will depend on a variety of factors including the rate of cost reduction of ASDs and corresponding market penetration, and the types of part- or variable-loads driven. Further, the individual savings achieved may depend on the development of new engineering design rules that fully exploit the opportunities presented by ASDs.

Pipes and Ducts

Pipes, ducts, and related fittings make up the final part of pump/fan systems, channeling the liquid or gas to where it is to be used. Appropriate design of a pipe/duct system can provide substantial energy savings in many applications.

In a pipe/duct system, energy is used to lift the liquid—water, petroleum, chemicals--or gas and to overcome friction in the pipe/duct and its fittings (including the throttling valve, if any). The energy required to lift the liquid/gas cannot be changed, but energy losses due to fiction and related effects can be dramatically reduced by increasing the diameter of the pipe/duct, by using smoother pipe,[59] and by careful choice and spacing[60] of the fittings used. The energy savings achievable must be balanced against the various costs associated with a smoother or larger pipe or duct. In a building, increased pipe and particularly duct size can have substantial costs associated with it—by increasing the space needed between floors or reducing usable space. In industry, the costs are more often limited to the increased capital costs of the pipe/duct and related components alone. In theory, many cost related factors could be included in the analysis to determine the optimum pipe/duct diameter--capital costs for the pipe/duct, fittings, support structure, pump/fan, and motor; taxes and insurance; and energy savings. In practice, the analysis usually considers only the increased capital and O&M costs of the larger pipe/duct versus the energy savings.[61]

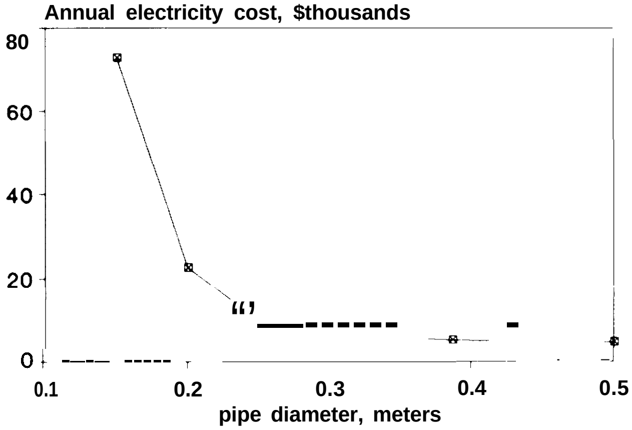
[58] For a brief review of this problem and various national standards for harmonic distortion from ASDs, see Samuel F. Baldwin, "EnergY-Efficient Electric Motor Drive Systems," Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), op. cit., footnote 27.

[59] For example, the friction factor for commercial steel pipe is 30 times linger than that for the same diameter PVC plastic pipe. The impact Of a larger friction factor on energy use varies, however, with pipe diameter, flow rates, and other factors.

[60] Proper spacing can reduce losses by as much as 30 to 40 percent.

[61] Eric D. Larson and Lars J. Nilsson, "Electricity Use and Efficiency In Pumping and Air-Handling Systems," paper presented at the American Society of Heating, Refrigerating, and Air Conditioning Engineers Meeting, June 23-25, 1991; Nicholas P. Cheremisinoff, "Piping," Technology Menu *for Efficient End-Use of Energy* (Lund, Sweden: Environmental and Energy Systems Studies, Lund University Press, 1989).

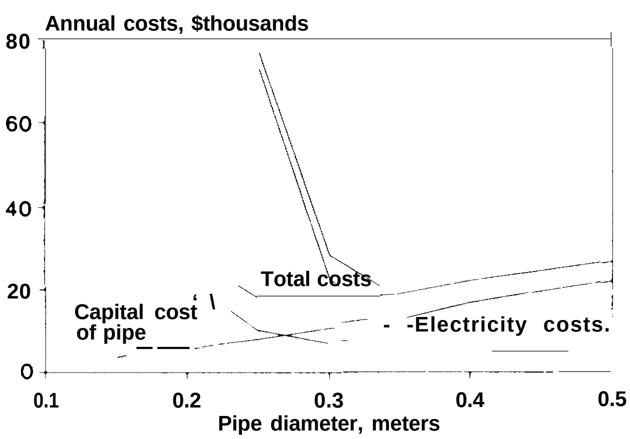
Figure 4-11 A—Reduction in Energy Required To Pump a Liquid Through a Pipe as a Function of Pipe Diameter



Assumptions: 6-meter static head; 30-meter friction head for 200 mm pipe diameter; 500-meter pipe; 90 l/s flow.

SOURCE: Nicholas P. Cheremisinoff," Piping," *Technology Menu For Efficient End-Use of Energy, Volume I: Movement of Material* (Lund, Sweden: Environmental and Energy Systems Studies, Lund University Press, 1989).

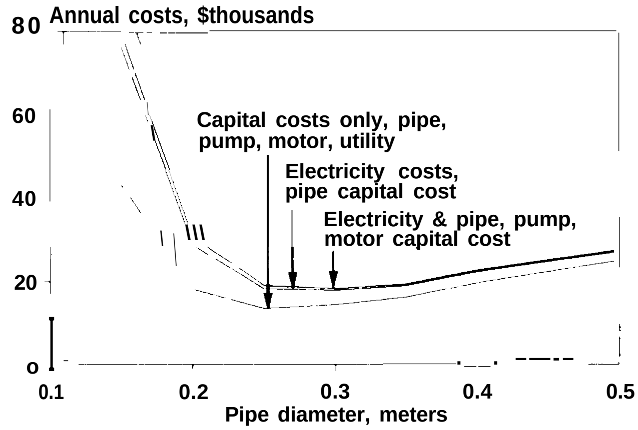
Figure 4-11B—Annualized Capital Cost of Pipe, Electricity Cost, and Sum of the Pipe Capital Cost and Electricity Cost



SOURCE: Nicholas P. Cheremisinoff," Piping," *Technology Menu For Efficient End-Use of Energy, Volume I: Movement of Material* (Lund, Sweden: Environmental and Energy Systems Studies, Lund University Press, 1989); and app. A of this report.

If, instead, the total system capital costs are considered—including the motor, pump, and upstream utility investment, then the optimum pipe/duct size will normally be increased compared to the case where only pipe capital and operating costs are considered. This is shown in figures 4-1 la, b, and c. The change in the optimum diameter shown in figure 4-11C may seem small, but it reduces electricity use

Figure 4-11 C—Annualized Total System Costs



This figure shows annualized total system costs for three different types of system accounting: 1) capital rests only, including the pipe, pump, motor, and utility generation, transmission, and distribution equipment; 2) capital costs of the pipe only plus the cost of electricity; 3) capital costs of the pipe, pump, and motor plus the electricity costs to operate the system. Arrows indicate the minimum total cost for the three cases indicated.

Different discount rates and electricity prices can shift these various optimum points to higher or lower diameters. In general, however, the optima are relatively insensitive to changes in these parameters. For example, varying discount rates from 7 to 21 percent and electricity y costs from $0.03 to 0.09 moved the optima from a low of 0.20 meter to a high of 0.30 meter. Over this same interval, electricity use varied by a factor of more than 3.

SOURCE: U.S. Congress, Office of Technology Assessment, 1992; see also app. A.

by one-third. It is also worth noting that, on all three accounting systems, the total cost is relatively flat from 0.2 meters to 0.5 meters. Over this same range, however, electricity use drops by a factor of 5 at the factory, or nearly 6 at the utility when transmission and distribution (T&D) losses are included.

Similar considerations apply to ducts. For building ventilation systems, new computerized design tools are being developed that minimize life cycle costs—including duct, fan, motor, and other capital costs, along with electricity costs. Compared to duct systems designed with today's conventional methodologies, case studies with these new design tools find total life cycle cost savings of roughly 20 to 50 percent and electricity savings of 25 to 55 percent at an increase in capital costs of 5 to 10 percent, depending on the particular parameters. Alternatively, for the same energy use, capital costs could be reduced by 20 percent or more compared to conventional designs.[62] Adjustable speed drives, high efficiency motors, and improved fans can provide additional savings, as outlined above.

Systems

These various opportunities for reducing electricity use are summarized in table 4-18. Just 4 percent of the input coal is converted to useful energy (to overcome static pressure drop) at the end of the piping, and losses are spread throughout the system. Thus, in this particular case, saving 1 unit of energy in piping system losses can save up to 25 units of energy worth of coal. ASDs achieve the greatest individual savings, and do so by eliminating shaft coupling and throttle valve losses, and by raising pump efficiencies by operating closer to the design point. Increasing the pipe diameter by 25 percent also offers large savings due to the high friction losses of this particular system and due to the great leverage such reductions have upstream in the system.[63]

Repeating the calculations for two-thirds flow gives similar savings: the increased throttling losses and reduced pump efficiency are roughly counterbalanced by decreased piping losses. For this particular system, combining all of the various improvements listed leads to electricity savings of some 65 percent (see table 4-18). Capital savings, however, would depend on the tradeoff between increased pipe size and decreased utility, motor, and pump size (see figure 4-1 1). The number of industrial or other systems in which such large savings can be found, however, is unknown but there are nevertheless many cases where reduced capital costs, reduced life cycle costs, and substantial energy savings are possible.

Many other motor drive system improvements are possible,[64] including the use of power factor correction capacitors or other devices, amorphous magnetic materials in distribution transformers and motor cores, and permanent magnet motors. For example, in India it has been estimated that power factor correction capacitors could reduce electricity demand for one-fifth the cost of building new supply .65

MODERN INDUSTRIAL PROCESSES

This section examines four large industries: steel, cement, pulp and paper, and chemicals (specifically fertilizer production). These industries are particularly important due to their role-especially steel and cement—in building national infrastructures of roads, buildings, and factories, and due to their very high energy intensities (see figure 4-1).[66] Other important industry-related energy issues, particularly the cogeneration of heat and electricity, are examined in chapter 6.[67]

Steel

Developing countries such as China, India, and Brazil devote about 20 percent—about the same as the OECD countries[68]--of industrial commercial[69] energy consumption to steel production. The top 10 producing countries account for about ***90*** percent of the crude steel made in the developing world; many other developing countries produce little or no steel.

Overall steel production has been increasing by a little over 7 percent per year in the developing countries (with a wide variation among individual countries), while remaining relatively constant in the industrialized countries (see figure 4-2). At current

@Robert J, Tsal, " Ducking,' Technology *Menu for Efficient End-Use of Energy* (Lund, Sweden: Environmental and Energy Systems Studies, Lund University Press, 1989).

63This does not, however, take into account changes in pump or motor efficiency, etc. It also does not provide for the complex tradeoffs in capital costs for larger pipe (less the smaller motor and pump) versus the energy savings.

64Samuel F. Baldwin, ' 'Energy-Efficient Electric Motor Drive Systems, " Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), op. cit., footnote 27.

65Inter-Ministerial Working Group, subcommittee reports, "Report on Utilisation and Conservation of Energy, " India, 1983.

&Due t. the complexity of these industries and the wide variety of technical approaches (depending on the particular national circumstances Of access to technology, capital, raw materials, trade policy, and a host of other factors), however, this will necessarily be a brief survey of these industries rather than an indepth examination.

67See also, U.S. Congress, Office of Technology Assessment, *Industrial and Commercial Cogeneration*, OTA-E-192 (Washington, « U.S. Government Printing Office, February 1983).

68 Maurice Y. Meunier and Oscar de Bruyn Kops, op. Cit., footnote 19.

69Commercial—primarily fossil or hydroelectric-energy as opposed to traditional biomass fuels used in many rural industries.

Table 4-18-Hypothetical Savings for Various Pumping System Configurations

	Baseline		Efficient system	
	eff[a]	rmn[b]	eff	rmn
Coal	NA	100%	NA	100%
Generation	33%	33	33%	33
Transmission and distribution	85	28	90	30
ASD	NA	NA	95	28
Electrical motor	90	25	93	26
Shaft coupling	98	25	98	26
Pump	75	19	80	21
Throttle valve	66	12	100	21
Piping system	35	4	56	12
Coal required	—	100 units	—	35 units
Savings	—	NA	—	65%

NA = not applicable.

[a]"eff" is the device efficiency in percent.

[b]"rmn" is the remaining energy as a percent of the starting total.

[c]"Savings" are the percentage point reductions in coal use made possible for the different component and system improvements while still providing the same useable energy at the end of the piping system.

Improvements include: an upgraded transmission & distribution system; an Adjustable Speed Drive (ASD); a high efficiency electric motor (note that the electric motor will lose up to a percentage point or so in efficiency due to harmonic generation by the ASD); an improved pump and operation of the pump at a higher intrinsic speed; the elimination of the throttle valve allowed by use of the ASD; and an increase in pipe diameter of 25 percent. Note that many baseline systems will have lower piping system losses than this example. For further details and additional potential improvements, see the reference.

SOURCE: Adapted from Samuel F. Baldwin, "Energy-Efficient Electric Motor Drive Systems," in *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

rates, steel production by developing countries will overtake that in the industrialized countries early in the next century. Developing countries are unlikely to use as much steel per capita as industrial countries did at their peak, however, as the performance of steel has increased substantially and there are now other lower cost and less energy intensive materials that can substitute for steel in many applications.

The energy efficiency of steel production in the developing countries varies widely. In some cases, it has significantly lagged that of the industrialized countries. Integrated steel plants in India and China currently use, on average, 45 to 53 gigajoules (GJ) (43 to 50 million Btus) per tonne of crude steel produced;[70] integrated steel plants in the United States and Japan use half as much energy. Some developing countries have made significant strides to reduce overall energy use in steel production. The Brazilians, for example, cut energy consumption from 34 GJ to 27 GJ per tome of crude steel between 1975 and 1979 and the South Korean steel industry is among the most efficient in the world.[71]

There are seven major processes in conventional steel production:[72] preparation of the ore, production of coke, ironmaking, steelmaking, casting (or primary finishing), forming (or secondary finishing), and heat treating.[73] The corresponding energy use of each process is listed in table 4-19 for a state-of-the-

[70]These figures d. not provide for differences in product mix, etc. For example, China produces much more cast iron than does the United States. Key plants in India, China, and elsewhere are often more efficient than these averages would suggest. In China, for example, energy use in key plants has been estimated at about 20 percent higher than that for the United States, if differences in the product mix are accounted for and the much more complex shaping and heat treating work done in the United States is ignored. If these differences in shaping and heat treatment are included, key Chinese plants use about one-third more energy than U.S. plants. Marc Ross and LiuFeng, "The Energy Efficiency of the Steel Industry of China," *Energy,* vol. 16, No. 5, 1991, pp. 833-848.

[71]Maurice Y. Meunier and Oscar de Bruyn Kops, op. cit., footnote 19; Sven Eketorp, "Energy Considerations of Classical and New Iron- and Steel-Making Technology,' *Energy,* vol. 12, No. 10/1 1, 1987, pp. 1153-1168,

[72]U.S. Congress, Office of Technology Assessment, *Industrial Energy Use,* OTA-E-198 (Springfield, VA: National Technical Information Service, June 1983).

[73]This list is, of course, oversimplified. Among other simplifications, it does not include such important developments as secondary metallurgy, etc. and it artificially divides the steelmaking and primary finishing steps which, with the use of continuous casting, might more logically be listed as one process.

art steel mill using cost effective, commercially proven technologies. At each stage, different processes may be employed-depending on local resources and capabilities, and the type of steel being produced—with different impacts on capital expenditures and energy consumption. These alternative processes, particularly the direct use of coal for producing iron and advanced casting and forming techniques for steel, may dominate the industry in the future. The discussion here will nevertheless follow the conventional process flow chart.

Ore Preparation

Ore is prepared by crushing and grinding it, and then agglomerating it by pelletizing/sintering processes into marble sized pieces that can be fed into a blast furnace. More energy efficient agglomeration processes have been developed, some of which also improve pellet quality.[74]

Coking

Heating coal to temperatures of 1,650 to 2,000‘F for 12 to 18 hours boils off its volatiles and leaves coke, a fairly pure (80 to 90 percent) carbon. The coke serves three purposes within the blast furnace: as fuel to heat and melt the ore/iron; to physically support the ore; and as a chemical reducing agent. To meet these needs requires coke that has a low impurity/ash content and that is physically strong.

The efficiency of converting coal to coke has improved substantially in recent years. In the United States, for example, the energy used to produce a metric tonne of coke declined from 7.0 gigajoules (6.7 million Btus) in 1980 to 4.1 GJ (3.9 million Btus) by 1989.[75] More efficient processes are becoming available. For example, the traditional process for stopping the chemical reactions in the coke ovens was to quench the coke with water and vent the steam into the atmosphere. A much more efficient technique is dry coke quenching, in which the hot coke in the ovens is cooled by circulating a nonoxidizing gas through it to stop the chemical reactions and at the same time to capture the heat from the coke to generate steam or electric power. This process also improves coke quality and reduces environmental emissions.[76] Dryquenching is in use in India and other countries.

Table 4-19—Energy Consumption in IISI Reference Steel Plants

	BF/BOF[a] GJ/tcs[c]	DRI/EA[b] GJ/tcs	Scrap/EAF GJ/tcs
Ironmaking	13.8	11.7	NA
Coke oven	1.6	NA	NA
Sintering	1.4	NA	NA
BF	10.6	NA	NA
Steelmaking	-0.01	5.5	4.8
Casting[d]	0.4	0.3	0.3
Forming	2.8	2.3	2.3
Other	1.1	0,2	0.2
Total	18.1	20.0	7.6

NA = Not available or not applicable.
[a]This is for case A, commercially proven technologies, rather than for the IISI base case because, for example, dry quench coke plants and EAF scrap preheaters are in operation. More generally, these reference plants incorporate "proven, energy efficient technologies and operating practices which should be considered economically viable in the majority of steelmaking countries."
[b]75 percent directly reduced iron (DRI) and 25 percent scrap.
[c]GJ/tcs is Gigajoules per metric tonne of carbon steel. Electricity is valued at 9.63 MJ/kWh or a conversion efficiency, fuel to electricity, of 37 percent.
[d]Casting includes continuous casting and primary rolling mills.
SOURCE: International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.

Charcoal is used in place of coke in roughly one-third of Brazilian ironmaking due to a lack of local coking coal and the lower cost of charcoal. In 1985, about 25 million tomes (t) of wood with an energy content of 0.45 exajoules (EJ) (or 0.43 Quad) were converted to charcoal in Brazil, primarily for use in metals production. Between 1974 and 1986, improved reforestation techniques and improved forestry productivity improved forestry yields by 3.5 times, while improvements in the blast furnaces lowered the specific consumption of charcoal from 3,4 m^3/t to 2.6 m^3/t of hot metal.[77] A large portion of the wood used for charcoal, however, is obtained by clearing natural forests, rather than fuelwood plantations, with significant environmental impacts. This

[74]Examples of improved pelletizing/sintering Processes include the MTU (Michigan Technological University), COBO (cold bonding), and Peridur processes for agglomeration, and various waste heat recovery schemes in the sintering process. See Sayed A. Azimi and Howard E. Lowitt, U.S. Department of Energy, "The U.S. Steel Industry: An Energy Perspective," Report No. DOE/RL/01830-T55 (Springfield, VA: National Technical Information Service, January 1988).

[75]Energetics, Inc., report for the U.S. Department of Energy, "Industrial Profiles: Steel," Report No. DE-AC01-87CE40762 (Springfield, VA: National Technical Information Service, December 1990).

[76]Jonathon P. Hicks, "The Search for a Cleaner Way to Make Steel," *The New York Times*, Mar. 21, 1990, p. D7.

[77]Francisco Lanna Leal and Benoni Torres, "The Iron and Steel Industry in Brazil," *Ironmaking and Steelmaking*, vol. 17, No. 1, 1990, pp. 1-7.

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has caused considerable controversy over the use of charcoal for ironmaking in recent years.[78]

Ironmaking

Blast furnaces are most often used to convert iron ore to metallic iron. In this case, iron-bearing materials are fed into the top of the blast furnace together with limestone/dolomite and coke for fuel. Heated air (and sometimes additional fuel) is blown into the blast furnace from the bottom. The coke (and possibly other fuel) burns in the hot air blast to heat, chemically reduce, and melt the iron as it descends through the furnace. The limestone/dolomite combines with impurities in the iron to form a slag that floats on the molten iron and can be removed. Blast furnace efficiencies have been improved by a variety of means, including the use of ''top pressure recovery turbines' to generate typically 8 to 15 megawatts of power using the pressure and heat from the blast furnace (see table 4-20).

A number of efforts are underway to directly produce iron with coal, rather than with coke. These processes would lower capital costs—by one-half to two-thirds compared to a similar sized 0.5 million metric tonnes per year plant, and by perhaps a third compared to a conventional plant six times larger—by avoiding coke ovens and, in some cases, agglomeration facilities. They would be more flexible, allow smaller scale operations, and would reduce environmental impacts. Energy requirements for these systems, however, range from about 13.3 GJ/t (12.6 million Btu/t) of hot metal for three-stage systems to as much as 30 GJ/t (28.4 million Btu/t) for single-stage systems. The low end of these energy requirements is about a 10-percent improvement over typical conventional blast furnaces and about 5 percent better than can be achieved with the best cost effective coke-based blast furnace technology available today. The high end has, however, much higher energy intensities than conventional best practice technologies today. Several of the systems make extensive use of electricity and thus suffer the conversion losses of fuel to electricity in generation and also carry a substantial additional capital cost for the generating facilities.[79] Coal based process plants are in operation in South Africa producing 300,000 tons per year.[80] These capital savings and other advantages may push direct coal-based processes into a dominant role in the steel industry of the future.

High quality iron ore can also be directly reduced to metallic iron (DRI) using natural gas. Direct reduction accounted for 85 percent of production in Venezuela[81] and 26 percent of Mexican production in 1986;[82] and for all of Indonesia's production.[83] Although direct reduction only accounts for 5 percent of Indian production, current construction will triple DRI capacity over the next several years.[84] There are also several DRI facilities in Africa.[85] Following direct reduction, the sponge iron is then converted to steel using electric arc furnaces.

Steelmaking

Steelmaking refines the pig iron produced in the ironmaking process. In steelmaking, chemical elements such as phosphorus, sulfur, and silicon are reduced and removed from the melt, and elements such as nickel, chromium, and other alloying agents are added to give the steel its desired properties.

Three types of furnaces are used to produce steel—the open hearth furnace, the basic oxygen furnace, and the electric arc furnace. The open hearth furnace is now outmoded—with higher capital costs, greater energy use, and lower productivity than the basic oxygen furnace-and is being phased out in most countries. By 1986, Korea and Taiwan had no production from open hearth furnaces, Brazil produced just 2.4 percent of its steel with open hearth

[78] Frank Ackerman and Paulo Eduardo Fernandes de Almeida, ' 'Iron and Charcoal: The Industrial Fuelwood Crisis in Minas Gerais, ' *Energy Policy*, vol. 18, No. 7, September 1990, pp. 661-668; Anthony B. Anderson, "Smokestacks in the Rainforest: Industrial Development and Deforestation in the Amazon Basin,'' *World Development*, vol. 18, No. 9, 1990, pp. 1191-1205.

[79] R.B. Smith and M.J. Corbett, ''Coal-Based Ironmaking," *Ironmaking and Steelmaking*, vol. 14, No. 2, 1987, pp. 49-75.

[80] ''COREX Comes Onstream,'' *Iron Age*, March 1990, p. 35.

[81] C. Bodsworth, ''The Iron and Steel Industry in Venezuela, ' *Ironmaking and Steelmaking*, vol. 16, No. 1, 1989, pp. 1-3.

[82] Organisation for Economic Cooperation and Development, *The Role of Technology in Iron and Steel Developments* (Paris, France: Organisation for Economic Cooperation and Development 1989).

[83] H.K. Lloyd, ''Steelmaking and Iron Ore Smelting in Indonesia," *Ironmaking and Steelmaking*, vol. 15, No. 2, 1988, pp. 53-55; T. Ariwibowo and Souren Ray, "Indonesia's Only Integrated Steel Plant—Krakatau Steel," *Iron and Steel Engineer*, January 1988, pp. 56-59.

[84] Amit Chatterjee, "The Steel Industry in India,'' *Ironmaking and Steelmaking*, vol. 17, No. 3, 1990, pp. 149-156.

[85] 'The Emergence of an African Iron and Steel Industry,'' *Ironmaking and Steelmaking*, vol. 16, No. 6, 1989, pp. 357-361.

Table 4-20-Energy Conservation Opportunities and Costs in the Steel Industry[a]

Technology	Capital cost U.S. $millions	Energy saved MJ/ts	Type	Cost of saved energy $/GJ primary energy
Automatic ignition of coke oven flare	0.3-0.6	13-30	Fuel	$0.22
Top gas recovery[b] turbine	15-22	250-315	Electricity	$0.66[c]
Hot stove waste heat recovery	3-4.5	60-100	Fuel	$0.47
BOF gas recovery	125-150	750-850	Fuel	$1.70
Double insulation of skids	0.9-1.5	40-55	Fuel	$0.27
Coke dry quench[d]	120-200	420-630	Steam/electricity	$3.10
Coke oven automobile combustion control	4.5-7.5	33-50	Fuel	$1.45
Sinter heat recovery	37-67	150-290	Steam/electricity	$2.38
BF Bled gas recovery	3-4.5	29-42	Fuel	$1.06
BOF gas waste heat recovery	22-37	80-120	Steam	$3.00

[a]Converted from approximate 1980 to 1990$; converted from Mcal to MJ at 4.1868 J/cal; Marginal cost calculated based on midpoint of cost and energy savings ranges, assuming a 30-year plant life and 7-percent discount rate for a CRF of 0.080586, and an annual plant production of 8 million tons of carbon steel per year.
[b]Note the cost of top gas recovery turbine seems very low, even for capital cost alone.
[c]$0.66/GJ for electricity valued in terms of primary energy; or $0.007/kWh for electricity itself.
[d]Note that Coke dry quench improves quality of coke.

SOURCE: International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.

furnaces, Mexico 12 percent, and Venezuela 18 percent. The share of steel produced in open hearth furnaces in India dropped to 68 percent by 1982/83 and to 47 percent in 1986/87, and is scheduled to be rapidly phased out after 1995. In China, open hearth furnaces accounted for only about one-quarter of production in 1988.[86]

Today's modern integrated plants—taking iron ore to finished steel—generally use basic oxygen furnaces (BOF). This process refines steel by blowing oxygen into the furnace to produce an intense chemical reaction.

Electric arc furnaces (EAF), which are used primarily to recycle scrap steel and to a lesser extent for DRI--have become increasingly important in recent years and are particularly attractive to developing countries because EAF-based minimills are economic at smaller scales than integrated plants using basic oxygen furnaces, and are less capital and (if the energy embodied in scrap is not included) less energy intensive per unit output. The drawbacks of EAF minimills include a limited set of products that can be produced—although this is changing with the development of thin slab casting;[87] the relatively high cost of electricity to power the arc furnaces (there is also a high upstream capital cost for generating plants); and the dependence on scrap (which may be in short supply in developing countries in the future) or on DRI.[88] Numerous minimills (including EAF and other operations) using steel scrap[89] have been established in developing countries. Korea and Taiwan each have about 50 minimills; Mexico has about 15;[90] and India and Brazil have over 150 each.[91]

The efficiency of EAFs can be improved by preheating scrap before it is fed into the furnace using the waste heat from the furnace,[92] by the use of ultra high power (UHP) electric arc furnaces, and

86 Energy and Environmental Analysis, Inc., "Conserving process Heat in Primary Industries of India and China," contractor report prepared for the Office of Technology Assessment, August, 1990; Amit Chatterjee, op. cit., footnote 84; Organisation for Economic Cooperation and Development, op. cit., footnote 82.

87 Michael Schroeder and Walecia Konrad, "Nucor: Rolling Right Into Steel's Big Time," *Business Week, No. 3188, Nov. 19, 1990*, pp. 76-79.

88 Maurice Y. Meunier and Oscar de Bruyn Kops, op. cit., footnote 19.

89 R. Berlekamp, "Scra~A Raw Material in Worldwide Demand for Steelmaking," *Ironmaking and Steelmaking, vol. 17, No. 2, 1990*, pp. 83-88. An interesting case study of scrap recovery can be found in: Mary Anne Weaver, "Great Ships Go To the Boneyard on a Lonely Beach in Pakistan," *Smithsonian Magazine*, vol. 21, No. 3, June 1990, pp. 3040.

90 Organisation for Economic Cooperation and Development, op. cit., footnote 82.

91 Amit Chatterjee, op. cit., footnote 84; Francisco Lanna Leal and Benoni Torres, op. cit., footnote 77.

92 Sayed A. Azimi and Howard E. Lowitt, U.S. Department of Energy, "The U.S. Steel Industry: An Energy Perspective," Report No. DOE/RL/O1830-T55 (Springfield, VA: National Technical Information Service, January 1988).

by other means.[93] UHP furnaces shorten the cycle time and correspondingly improve furnace productivity and reduce energy use due to the shorter period at high temperature.[94] At the same time, however, UHP furnaces have higher power demand. This can put added strain on utilities that are already often short of capacity. Indeed, from 1976 to 1986, steel minimills in India were supplied with just 38 percent of the power they would need to be at full production.[95]

Energy use in many steel minimills in developing countries is much higher than that in the industrial nations. For example, the energy consumption in Indian minimills is typically 600 to 900 kilowatt-hours (kWh)/t versus as low as 400 kWh/t elsewhere. Many of the steel operations in developing countries, however, are unable to take advantage of proven energy conserving and productivity enhancing technologies due to their small scale and inadequate infrastructure. The average size of minirnills in India is typically below 15 tomes capacity, compared to 80 to 300 tonnes elsewhere. At such small scales, the capital costs for scrap preheater and other technologies increase rapidly per unit output.

Casting

Casting or primary finishing includes casting and initial rolling of the steel into slabs for flat sheets, and blooms (rectangular) or billets (square) for structural shapes and bars. Ingot casting is done by pouring the liquid steel into molds to form ingots before reheating and initial rolling. Continuous casting pours the liquid steel directly into its semifinished shape, eliminating the intermediate steps of ingot casting and reheating.

Continuous casting has rapidly come to dominate the steel industry because it significantly lowers/eliminates capital investment for the stripper, reheating (soaking pit), and primary rolling mill; substantially reduces energy use (by 400 to 1,400 million joules (MJ)/tonne or 380 to 1,325 thousand Btus); gives a typically 5 to 10 percent or greater increase in yield—less metal must be scrapped as waste with corresponding energy savings-at often higher quality; and reduces emissions associated with ingot casting and heating.[96] As of 1986, several developing countries had higher shares of continuous casting than the United States (55 percent> Korea 71 percent, Taiwan 88 percent, and Venezuela 71 percent; was comparable-Mexico 54 percent; or was slightly lower—Brazil 46 percent.[97] This capacity was largely developed in just a 10-year time period, from the mid-1970s to the mid-1980s. In contrast, all crude steel in integrated plants in India was ingot cast until 1982-83; only 10 percent of steel production was continuous cast as of 1986-87. Similarly, in China about 15 percent of steel was continuously cast by 1988.[98]

Other advances (at various stages of development) in casting offer even greater potential capital and energy savings, and productivity improvements. These include: thin slab casting;[99] thin strip casting;[100] net shape casting; and spray steel.[101]

Forming

Forming or secondary finishing transforms the steel into its final shape through a series of reheating, hot rolling, and cold rolling steps. Overall, hot rolling of strip, cold reduction, and finishing operations each consume about 125 kWh/t. Hot rolling thin cast strip to cold-rolled gages in an inert atmosphere could eliminate a series of scale re-

93 L.L. Teoh, "Electric&c Furnace Technology: Recent Developments and Future Trends," *Ironmaking and Steelmaking,* vol. 16, No. 5, 1989, pp. 303-313; Dick Hurd and John Kollar, "A Growing Technology in Electric Steelmaking," Electric Power Research Institute Center for Materials Production, Carnegie Mellon Research Institute newsletter, Pittsburgh, PA, January 1991.

94 Sven Eketorpe, "Electrotechnologies and Steelmaking," Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.), *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989), pp. 261-296.

95 Amit Chatterjee, op. cit., footnote 84.

96 Sayed A. Azimi and Howard E. Lowitt, op. cit., footnote 92.

97 Organisation for Economic Cooperation and Development, op. cit., footnote 82.

98 Energy and Environmental Analysis, Inc., Op. Cit., footnote 86.

99 Michael Schroeder and Walecia Konrad, "Nucor: Rolling Right Into Steel's Big Time," *Business* Week, No. 3188, Nov. 19, 1990, pp. 76-79.

100 Sayed A. Azimi and Howard E. Lowitt, op. cit., footnote 92.

101 Gary McWilliams, "A Revolution in Steelmaking?" *Business Week, No. 3179,* Sept. *24, 1990,* pp. 132-134.

moval, cleaning, and annealing steps and ultimately save 50 to 100 kWh/t.[102]

Heat Treating

After secondary finishing, the steel is again reheated and then allowed to cool slowly in order to relieve the stresses built up in the steel in the above rolling processes. This improves the strength and ductility of the final product. Heat treatment has also seen considerable efficiency gains in recent years. In the United States, energy consumption of heating and annealing furnaces dropped by nearly one-third between 1980 and 1989.[103] Continuous annealing and processing systems can further reduce energy use by about 460 to 700 MJ/tonne (440 to 660 thousand Btu) by combining five cold rolling batch processes into one.

By employing all currently cost-effective technologies, energy consumption in integrated steel mills can be reduced to about 18 GJ/tonne (17 million Btu), and to about 7.6 GJ/tonne (7.2 million Btu) in scrap fed electric arc furnaces (see table 4-19). The best steel mills in the world approach these levels of efficiency, including Japanese, U. S., South Korean, and others. Countries such as Brazil, Venezuela, and other industrializing countries are not far behind; while India and China have a considerable ways to yet go to reach these levels of efficiency.[104]

In the future, the steel industry could change dramatically from the above, particularly with the widespread introduction of processes for the direct production of iron from coal, greater use of electric arc furnaces, and extensive use of thin slab casting or other such techniques.

Cement

The cement industry typically consumes 2 to 6 percent, and sometimes more, of the commercial energy used in developing countries.[105] The use of cement is expected to increase rapidly as national infrastructures of roads, bridges, and buildings are developed. Considerable effort is now being devoted to developing higher performance cements to ensure that this huge investment in infrastructure lasts a long time.[106] Despite the energy intensity Of Cement production, it is one of the least energy intensive construction materials when in its final form of concrete/aggregate (see tables 4-21, 4-22).

Table 4-21—Average Energy Intensities of Building Materials

Material	Energy intensity (MJ/kg)
Concrete aggregate	0.18
Concrete	0.8
Brick and tile	3.7
Cement	5.9
Plate glass	25.0
Steel	28.0

SOURCE: Mogens H. Fog and Kishore L. Nadkarni, "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries," World Bank Technical Paper No. 17, Washington, DC, 1983.

The value of cement is quite low compared to its weight. Because of this and because the raw materials for cement—limestone, various clay minerals, and silica sand—are widely available, cement is usually produced relatively near its point of use. In the United States, the maximum range for truck shipments of cement is about 300 km. In developing countries, where the transport infrastructure is less well developed, economical transport distances are often less. In China, for example, 150 to 200 km is the typical limit of transport; if transport over longer distance is needed, the construction of a new cement plant in the local area will be considered.[107] Thus, as a result of inadequate transport infrastructures, cement plants are often small and relatively inefficient.

The energy required to produce cement varies widely with the type of production process (see figure 4-12), quality of raw materials, plant management, operating conditions, and other factors. The performance of cement plants in developing coun-

[102] W.L. Roberts, Electric power Research Institute, *Power* Utilization *in* F/arf'recessing *of Steel*, Report No. EM-5996 (Palo Alto, CA: Electric Power Research Institute, January 1989).

[103] Energetics, Inc., op. cit., footnote 75.

[104] Energy and Environmental Analysis, Inc., Op. Cit., footnote 86.

[105] Mogens H. Fog and Kishore L. Nadkarni, "Energy Efficiency and Fuel Substitution in the Cement Industry With Emphasis on Developing Countries," World Bank Technical Paper No. 17, 1983.

[106] F., example, high performance cements are being developed at the Center for the Science and Technology of Advanced Cement-Based Materials, Northwestern University, Evanston, IL.

[107] Li Taoping, "Cement Industry in China," *Rock Products*, February 1985, p. 32.

Table 4-22—Energy Intensities of End Products Using Alternative Building Materials, MJ/m²

Structure	Concrete	Steel	Asphalt	Brick
Building wall. . . . . ,	400	NA	NA	600
Bridge	4,000	8,000	NA	NA
Roadway ... , ...	800	NA	3,000	NA

NA = Not available or not applicable.

SOURCE: Mogens H. Fog and Kishore L. Nadkarni, "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries," World Bank Technical Paper No, 17, Washington, DC, 1983.

tries also varies widely. Many plants approach the efficiency of the best in the industrialized countries, depending on when they were built and the conditions under which they are operated. Others show significant inefficiencies-using 25- to 50-percent more energy than efficient plants of the same type and with the same quality of raw materials input.[108]

The manufacture of cement involves three basic processes: the mining and preparation of the raw materials; clinker production; and finish grinding. Portland cement typically accounts for most of the cement in use. It consists of limestone (calcium carbonate), silica sand, alumina, iron ore, and small quantities of other materials. These materials are quarried, crushed, and mixed together, and are then processed at high temperatures--l,500 °C—in a large rotary kiln to produce marble sized pellets known as clinker. These pellets are then ground into a fine powder and mixed with gypsum for use as cement.

The two primary manufacturing processes are known as the wet and the dry processes. In the wet process, water is added to the raw materials so that the material fed into the kiln is a slurry. The wet process has been largely abandoned in recent years in favor of the dry process. In the dry process, the material fed into the kiln is a dry powder. Refinements in the dry process in recent years have focussed on making better use of the waste heat from the kiln to dry and preheat the material fed into the kiln-the preheater and precalciner processes. These have led to significant improvements in the overall energy efficiency of cement production. The relative fuel use of the wet and dry processes, however, differ considerably, with the dry process using somewhat more electrical energy and substantially less thermal energy.

Electricity use in cement production has increased in recent years due to the shift to the dry process, the use of more environmental controls, and more extensive use of preheater, which require large fan systems working at high pressure drops. The move towards higher strength cements in recent years has also required additional electricity use in order to more freely grind the clinker.[109] On the other hand, less cement may be needed if higher strength types are used, reducing total energy consumption.

Regardless of the process, typically 80 to 85 percent of the total energy used in cement production is for high temperature processing. The rest is largely for grinding or related steps. A variety of different fuels are used in cement production, including, oil, coal, gas—together accounting for about 70 percent of the total energy used, and electricity-accounting for about 30 percent of the total energy used (on a primary energy basis).[110] In addition, Brazil has made extensive use of charcoal, and biomass gasifiers have been used in Finland (see ch. 6).[111]

The energy used in producing cement varies widely by country, depending primarily on what fraction of total cement production is done by the more energy efficient dry process. In 1980, the U.S. cement industry used about 5.86 GJ (5.6 million Btus) per tome of cement, compared to 3.45 GJ (3.3 million Btus) per tonne for Japan and West Germany. The U.S. cement industry was then half wet process compared with 5 percent wet process in West Germany. Many developing countries are

108 Mogens H. Fog and Kishore L. Nadkarni, op. cit., footnote 105. See figure 5-1, p. 39.

109 Stewart W. Tresouthick and Alex Mishulovich, 'Energy and Environment Considerations for the Cement Industry, ' paper presented at the Energy and the Environment in the 21st Century conference, Mar. 26-28, 1990, Massachusetts Institute of Technology, Cambridge, MA.

110 Stewart W. Tresouthick and Alex Mishulovich, Ibid.

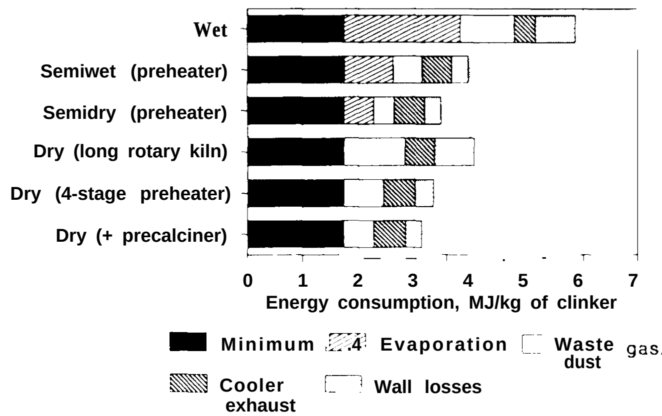
111 Hannu Lyytinen, 'Biomass Gasification As a Fuel Supply for Lime Kilns: Description of Recent Installations, *Tappi Journal*, vol. 70* No. 7, July 1987, pp. 77-80.

making rapid strides to improve the efficiency of their cement plants. Turkey, Tunisia, and the Philippines use the wet process for less than one-quarter of their cement production, with corresponding energy savings.[112] In Brazil, use of the @process increased from 20 to 80 percent of production between 1970 and 1987.[113]

Similarly, most recent capacity additions in India have been the dry process. This resulted in the wet process share of the total dropping from about 70 percent in 1970 to 37 percent in 1984. The average kiln size in India has also increased; and large kilns tend to be more efficient than small ones. In the 1970s, the average wet process kiln size was around 400 tonnes per day and new kiln capacity for the dry process averaged about 750 tonnes per day. In the 1980s, new dry process capacity has averaged 1,800 tonnes per day, comparable to industrial countries.[114] Most Indian cement capacity is in large plants, totaling some 55.4 million tonnes per year capacity in 1988/89 spread over 96 plants operated by 49 companies. About 84 percent of this capacity is privately held. During the 1980s, mini-cement plants have also been established to make use of small and scattered limestone deposits and to meet local demands.

Energy costs are a large part of the total production cost for cement; consequently there is a significant push to save energy. In India during 1983/84, energy costs were about 44 percent of total production costs for wet process plants and 39 percent of the total for dry process plants. In response, 10 large scale plants have been or are being converted from the wet process to the dry process in recent years, and precalcinators have been installed on 35 kilns in 23 plants. A variety of other improvements are also being made, including the extensive installation of instrumentation to monitor processes and automatic controls to improve control and product quality; improved refractory materials

Figure 4-1 2—Energy Consumption for Alternative Cement Production Systems



SOURCE: Mogens H. Fog and Kishore L. Nadkarni, "Energy Efficiency and Fuel Substitution in the Cement Industry with Emphasis on Developing Countries," World Bank Technical Paper No. 17, 1983.

on the kilns; waste heat recovery systems; improved grinding equipment; and cogeneration equipment.[115]

Factors that contribute to the low efficiency of Indian cement production include low quality coal and limited, poor quality (variable voltage and frequency) electricity supply from the State utility grid. To compensate, the cement industry had installed 545 megawatts (MW) of captive generation capacity by 1988/89 with another 100 MW under construction.[116]

Cement production in China reached 145 million tonnes in 1985. Of the 366 rotary kilns in use, 235 used the dry process. Of these, 33 had preheater and 11 had precalcinators. Cogeneration systems were used on about 50 of these kilns. There were also more than 4,000 vertical shaft kilns in use in 1985, providing about two-thirds of the total output of cement. Vertical shaft kilns are used primarily by smaller cement plants and can have lower efficiencies.[117] Average capacity of Chinese vertical shaft kilns is about 30,000 tomes/year. *18

[112]Mogens H. Fog and Kishore L. Nadkarni, op. cit., footnote 105, see figure 5-1, p. 39.

[113]Howard S. Geller and David Zylbersztajn, "Energy Intensity Trends in Brazil," *Annual Review of Energy,* vol. 16, 1991, pp. 179-203.

[114]Energy and Environmental Analysis, be., Op. Cit., footnote 86.

[115]Energy and Environmental Analysis, Inc., op. cit., footnote 86. Reported overall energy efficiencies of the Indian cement industry, however, have not improved much *over the time* period 1978-79 to 1983-84. Ministry of Industry, Bureau of Industrial Costs and Prices, Government of India, "Report on Energy Audit of Cement Industry," *Studies on the Structure of the Industrial Economy,* vol. 14 (New Delhi, March 1987).

[116]Energy and Environmental Analysis, Inc., Op. Cit., footnote 86.

[117]Energy and Environmental Analysis, Inc., op. cit., footnote 86. The data listed are, however, somewhat contradicted by that Of the earlier report: Li Taoping, op. cit., footnote 107. The data in the report by Taoping are also inconsistent internally, so have not been included here.

[118]D.F. Stewart and B. Muhegi, "Swategles for M fig Tanzania's Future Cement Needs," *Natural Resources* Forum, November 1989, pp. 294-302.

Although they have been largely abandoned in the industrial countries, vertical shaft kilns are used widely in China and might be practical in other countries. These plants offer lower installed capital costs and thus can serve smaller, dispersed markets.[119] On the other hand, the energy efficiency of vertical shaft kilns is typically low but potentially could be improved; and the product quality is often uneven due to poor distribution of raw materials within the kiln and interactions with the walls of the kiln. These problems might be redressed with further development and would allow more widespread use of this system.[120]

The Tanzanian cement industry was producing at just 22 percent of rated capacity by 1984, compared to 100 percent or better just 10 years earlier. Factors contributing to this decline in performance included:

- the lack of foreign exchange resulting in the frequent nonavailability of critical spare parts and other equipment when needed, resulting in delays and even complete shutdowns;
- inadequate industrial infrastructure resulting in long delays in making repairs at the few local workshops capable of doing the work;
- transport shortages and bottlenecks in providing raw materials; and
- shortages of skilled manpower in designing, constructing, and maintaining the plant and equipment.[121]

Substantial efficiency improvements above that of today's dry process are still possible. The grinding process, for example, is very inefficient, variously estimated at 2- to 5-percent efficient in breaking clinker apart into fine powder, the remainder goes into heat and vibration. A variety of improvements, including better separation and grinding equipment, and improved controls have reportedly raised grinding efficiencies by as much as 40 percent in some cases (see table 4-23).[122]

Similarly, there are numerous potential improvements in the high temperature processing of cement (see table 4-24). These efficiency improvements can reduce total system capital costs as well as operating costs. Other energy conservation opportunities include waste heat recovery, cogeneration, and the use of ASDs on kiln fan motors and other motor driven equipment.[123]

Table 4-23-Technology Improvements in Grinding

Technology	Average Potential energy savings (percent)
High efficiency classifiers	15
Roller mills	20
Controlled particle size distribution	27
Advanced mill internals	5
Separate grinding of components	5-1o
Computer control	15
High performance sensors, including on kiln exhaust	NA
Nonmechanical comminution	NA
Total	40

NA = not available or not applicable.

SOURCE: Stewart W. Tresouthick and Alex Mishulovich, "Energy and Environment Considerations for the Cement Industry," Energy and the Environment in the 21st Century, March 26-28, 1990, Massachusetts Institute of Technology, Cambridge, MA.

Many cement plants operate with minimal environmental controls and poor quality raw material inputs can further impede cleanup. For example, the use of coals with high ash contents leads to poor combustion in some cases and consequently generates a high carbon monoxide content in the exhaust gases coming off the kiln. These gases will trip safety mechanisms in electrostatic precipitators to prevent an explosion, resulting in the venting of large amounts of dust. Properly functioning controls can, however, provide substantial benefits. For example, a typical rotary kiln without any dust controls can lose 110 to 125 kg of dust per tonne of clinker processed, or equivalently, an efficiency loss of11 to 12 percent of the kilns output. Capturing this dust translates directly into a productivity increase

119 Sanjay Sinha, ''s@ Versus Large in the Indian Cement Industry—David and Goliath Hand-In-Hand, ' Marilyn Carr (cd.), *Sustainable Industrial Development* (London: Intermediate Technology Publications Ltd., 1988), pp. 128-150.

120 D.F. Stewart, ''Options f_or cement Production in Papua New Guinea: A Study in Choice of Technology, "*World Development*, vol. 13, No. 4,1985, pp. 639-651.

121 D.F. Stewart and B. Muhegi, op. cit., footnote 118.

122 Stewart W. Tresouthick and Alex Mishulovich, op. cit., footnote 109.

123 Tore R. Nilsson, Bengt Sinner, and Ola V. Volden, ''Optimized Production and Energy Conservation,'' *IEEE Transactions on Industry Application*, vol. IA-22, No. 3, 1986, pp. 442-445.

Table 4-24—Technology Improvements in Pyroprocessing

Technology	Average potential energy savings (percent)
Computer control	3-1o
Fluidized-bed reactor	10-30
Relaxed alkali specification	2-4
Low pressure-drop preheater	5
Advanced sensors. .,	2-5
Advanced preheater/precalciner,	5-1o
New mineralogical content of clinker	5-30
Total	NA

NA = Not available or not applicable.

SOURCE: Stewart W. Tresouthick and Alex Mishulovich, "Energy and Environment Considerations for the Cement Industry," Energy and the Environment in the 21st Century, Mar. 26-28, 1990, Massachusetts Institute of Technology, Cambridge, MA.

for the plant.[124] In modest quantities cement dust does not, however, cause particular damage to soils around the plant.

Pulp and Paper

Between 1961 and 1986, world paper production increased from about 78 million to 203 million tons annually. Developing countries produced about 16 percent of 1986 world paper output, Eastern Europe and the Soviet Union produced about 8 percent, and the remainder was produced in the OECD countries. Annual production in the developing countries, however, increased at an annual rate of about 7.3 percent between 1961 and 1980; in contrast, annual production in the industrial OECD countries increased at just 2.8 percent between 1971 and 1980.[125] At these rates, paper production by developing countries will overtake that of the industrialized countries by roughly 2020.

In the OECD countries in 1981, paper was the fourth largest industrial energy user, ranking behind iron and steel, chemicals, and petrochemicals, but was just ahead of cement.[126] Pulp and paper production is relatively less important in developing countries today due to the low rate of usage, but it is likely to become increasingly important in the future. In addition, the pulp and paper industry has the potential to become a significant generator of electricity for developing countries through the use of cogeneration systems supplied by captive waste products, especially bark and black liquor.

Papermaking typically consists of five process steps: wood preparation; pulping; bleaching; chemical recovery; and papermaking, The products produced include high quality writing and magazine paper, newsprint, tissue paper, cardboard, and various types of building construction papers.

Wood preparation consists of removing the tree bark and chipping the wood into small pieces. Pulping breaks apart the fibrous components of the wood into a form useful for making paper, This can be done through a variety of means. Most often chemical processes are used, but mechanical or other means are also employed perhaps 20 percent of the time. Each pulping process has certain advantages and disadvantages in terms of the quality, strength, cost, yield, and other attributes of the resulting paper produced. The residue from the chemical pulping process, i.e., the components of the wood that are not converted to pulp, is known as black liquor and is a large source of energy. Bleaching is often used to whiten the pulp before making paper (but is not necessary for paperboard and some other products). The papermaking process deposits the bleached pulp fibers in a sheet on a screen, drains and presses the water from it, and dries the sheet.[127] Table 4-25 lists energy consumption in pulp and paper mills in a variety of countries.

Table 4-26 compares energy use by paper mills using today's current mix of technologies for the United States, state-of-the-art paper mills, and advanced technologies. Substantial reductions in energy use are possible. Many of the technical improvements also lead to improved product quality. For example, improved presses (e.g., the extended nip press) used to squeeze the water out of the

124 Sanjay Sinha, op. cit., footnote 119.

125 Andrew J, Ewing, 'Energy Efficiency in the Pulp and Paper Industry With Emphasis on Developing Countries, ' World Bank Technical Paper No. 34, 1985; and " 1986-87 The World's Pulp, Paper, and Board Industry: Production and Trade, " *Pulp and Paper International,* July 1988, pp. 50-51.

126 In the OECD countries in 1981 the industrial energy use rankings were: steel—174 million tons oil equivalent (mtoe); chemicals—123 mtoe; petrochemicals— 122 mtoe; pulp and paper—58 mtoe of commercial energy purchased, but probably twice this amount was consumed by this sector, the remainder *coming* from the use of waste products generated by the mills—such as bark and other materials; cement--49 mtoe. Source: Andrew J. Ewing, Ibid.

127 For a more detailed description, see: U.S. Congress, Office of Technology Assessment, *Industrial Energy Use,* OTA-E-198 (Springfield, VA: National Technical Information Service, June 1983).

Table 4-25-Energy Consumption in Selected Pulp and Paper Mills

	Coverage		Average energy consumed	
Country	No. of mills	Percent of production	Purchased GJ/tp	Total GJ/tp
Colombia	4	80	34.6	50.3
Turkey	7	89	45.7	NA
India	4	13	79.4	112.0
Pakistan	5	90	56.3	59.7
Indonesia	15	38	33.2	50.3
Thailand	1	25	20.3	25.4
Average	NA	NA	38.3	54.0
OECD average	NA	NA	19.8	30.0

NOTE: these values of GJ/tonne of paper are below those listed in table 4-26 due to differences in definition, accounting conventions, assumed product mix, and other factors. The important feature to note is the relative performance—that the OECD average energy consumption is just over half that of the developing countries listed, and in table 4-26, that using advanced technologies can nearly halve energy consumption again, compared to the U.S. average.

SOURCE: Andrew J. Ewing, "Energy Efficiency in the Pulp and Paper Industry With Emphasis on Developing Countries," World Bank Technical Paper No. 34, 1985.

Table 4-26--Energy Use by Alternative Paper Production Technologies, United States

	Specific energy use, GJ/ton[a]		
Process	1988 average	State-of-the-art	Advanced technology
Wood preparation	0.48	0.40	0.40
Pulping	10.53	7.29	6.90
Bleaching	3.27	2.44	2.20
Chemical recovery	7.93	5.04	3.75
Papermaking	15.18	10.30	8.40
Auxiliary	3.41	3.12	3.12
Total	40.80	28.60	24.80

[a]These are averages for the net plant output. Energy requirements of individual processes can vary significantly from these averages depending on the type of paper product, reuse of waste streams within the plant, etc.

SOURCE: A. Elaahi and H.E. Lowitt, "The U.S. Pulp and Paper Industry: An Energy Perspective," April 1988, U.S. Department of Energy, Office of Industrial Programs, Report No. DOE/RL/01830-T57; Energetics, Inc. "Industry Profiles: Paper," U.S. Department of Energy, Office of Industrial Technologies, December 1990.

paper before drying, both reduce energy use by reducing the amount of water that must be evaporated and also improve fiber-to-fiber bonding, resulting in a sheet with higher strength. Alternatively, the same strength could be maintained while using lower grade-and less energy intensive-pulp. A large amount of electrical energy can be saved through the use of improved motor drive systems. Similarly, much of the process heat can be recovered through the use of various types of heat exchangers and recuperators, and through vapor recompression systems. The use of enzymes derived from wood rot funguses rather than traditional chemical or mechanical pulping might save a large amount of energy as well. Energy savings in the pulping process of 28 percent by using such enzymes compared to mechanical pulping have been demonstrated in Sweden.[128]

Of equal importance to conservation efforts within the plant is that the pulp and paper industry can greatly increase the amount of energy produced from its waste products. The typical pulp and paper operation has three principal waste streams that can provide energy: hog fuel, black liquor, and forest residues. Hog fuel is the bark, sawdust, and other scrap produced in reducing logs to feedstock for the pulping process. Hog fuels could supply about 3 GJ

[128]A. Elaahi and H.E. Lowitt, U.S. Department of Energy, Office of Industrial Programs, "The U.S. Pulp and Paper Industry: An Energy Perspective,' Report No. DOE/RL/01830-T57, April 1988.

[129]As measured at one pulp mill in Sweden.

(2.8 million Btu) per tonne of pulp produced (GJ/tp).[129] Black liquor, from the chemical pulping process, averages an energy content of about 13 GJ (12.3 million Btu) per tome of pulp. Other residues are currently left in the forest when harvesting the trees. A portion of these forest residues might be collected, but the long term impact this would have on forest soils would need to be examin ed closely. If fully recovered, the estimated energy content of forest residues would be about 25 GJ/tp (23.7 million Btu/tp). Combined, these energy resources total some 41 GJ/tp (38.9 million Btu/tp).[130]

Most kraft pulp mills (which use the chemical process resulting in the production of black liquor) currently use black liquor for cogenerating steam and electricity onsite. High efficiency steam injected gas turbine or combined cycle technology (see ch. 6) might be able to generate as much as 4,000 kWh of electricity per ton of pulp produced if all of the hog fuel, black liquor, and recoverable forest residues were used. Onsite needs today are typically about 740 kWh/tp of electricity plus some 4,300 kg/tp of steam, with the potential for significant reductions as discussed above. This would leave a substantial amount of power that could be sold to the grid. At $0.09/kWh, the saleable electricity (in excess of plant requirements) would have a value of some $230, equal to half the value of the pulp sold.[131]

Current and future research opportunities include the utilization of black liquor (physical, chemical and combustion properties), biological pulping, process monitoring and control, impulse drying of paper, advanced waste heat recovery, and others.[132]

Chemicals

The chemicals industry is extremely complex, involving the production of thousands of products in numerous competing processes. Moreover, the feedstocks and energy inputs into the chemical industry are often the same. Because of this complexity, the following discussion will be limited solely to the production of nitrogen based fertilizers, and will also serve as a transition to the discussion on the use of energy in the agricultural sector. More detailed reviews of energy use in the chemicals industry can be found elsewhere.[133] Finally, the use of electricity in the chemicals industry is dominated by pump, fan, compressor, and related mechanical drive needs. The above discussion of motor drive is directly applicable to these uses.

As of 1980, the energy used to produce fertilizers was about equal to all the commercial energy uses in the agricultural sector of the developing countries (not including China). Nitrogen fertilizers account for almost three-fourths of the energy consumption in the fertilizer sector, and nearly one-fifth is for packaging, transportation, and field application. The remainder is for phosphates (5 percent) and potash (3 percent). The production of nitrogen fertilizers is particularly energy intensive, and so will be the focus here.[134]

Nitrogen fertilizers are made primarily from ammonia. Energy use to produce ammonia has dropped from about 80 GJ/tonne (76 million Btu/t) of ammonia in the early 1940s to about 40 GJ/t (38 million Btu/t) for the average plant in the mid- 1970s, to as low as 33 GJ/t (31 million Btu/t) today. The theoretical limit is about 21 GJ/t (20 million Btu/t); the practical limit has been estimated at about 28.5 GJ/t (27 million Btu/t). The fuel component of this total energy consumption is usually provided by natural gas, which serves both as a feedstock and as a fuel. Currently, about 80 percent of world ammonia production is done by chemically reforming natural gas. The (externally purchased) electric power component of this total energy consumption dropped from about 800 kWh/tonne in the early 1960s to about 20 kWh per tonne in the early 1980s. This large drop in electricity usage was made possible by the transition from reciprocating com-

130 Eric D. Larson, "prospects for Biomass-Gasifier Gas Turbine Cogeneration in the Forest Products Industry: A Scoping Study," Princeton University, Center for Energy and Environmental Studies Working Paper No. 113.

131 Eric D. Larson, ''Biomass-Gasifier/Gas-Turbine Applications in the Pulp and Paper Industry: An Initial Strategy for Reducing Electric Utility CO_2 Emissions," paper presented at the Conference on Biomass For Utility Applications, Electric Power Research Institute, Tampa, FL, Oct. 23-25, 1990; Eric D. Larson, "Prospects for Biomass-Gasifier Gas Turbine Cogeneration in the Forest Products Industry: A Scoping Study, " Princeton University, Center for Energy and Environmental Studies Working Paper No. 113.

132 A. Elaahi and H.E. Lowitt, op. cit., footnote 128.

133 U.S. Congress, Office of Technology Assessment, op. cit., footnote 127; Energetic, Inc. for the U.S. Department of Energy, Office of Industrial Technologies, ' 'Industry Profiles: Chemicals, " Contract No. DE-AC01-87CE40762, December 1990.

134 Roger Heath, John Mulckhuyse, and Subrahmanyan Venkataraman, "The Potential for Energy Efficiency in the Fertilizer Industry, 'World Bank Technical Paper No. 35, 1985.

Table 4-27—Efficiency Improvements in Nitrogen Fertilizer Production

	Energy savings	Capital cost ($millions)
Purge gas recovery	1.8 GJ/mt	$1.4
Synthesis convertor	1.12 GJ/mt	
Molecular sieves	0.6 GJ/mt	$1.8
Power recovery turbines	10 kWh/mt	$0.35
Combustion air preheater	1 GJ/mt	$3.5
Surface condenser cleaners	NA	NA
Carbon dioxide removal	NA	
Use of flare gas	NA	$0.15
Feedstock saturation	0.6 GJ/mt	NA

NA = not available or not applicable; mt = metric tonne.
SOURCE: Roger Heath, John Mulckhuyse, and Subrahmanyan Venkataraman, "The Potential for Energy Efficiency in the Fertilizer Industry," World Bank Technical Paper No. 35, 1985.

pressers to centrifugal compressors and the extensive use of cogeneration from the high pressure steam.[135] Many more efficiency improvements are still possible as shown in table 4-27.

In many cases, pollution control measures in fertilizer plants have simultaneously allowed increases in production and reductions in energy use. Purge gas recovery and recycling, for example, captures hydrogen lost from the synthesis process, reducing fuel use and the need for compression. Typical savings are 1.8 GJ/t (1.7 million Btu/t) of ammonia at an installed cost of $1.4 million. These units are now standard in new plants. For a typical 1,000 tonne per day plant, some 600,000 GJ (570 billion Btu) would be saved annually. Over a 20-year plant lifetime, savings would total 12.6 million GJ (12 trillion Btu), at a discounted cost of about $0.25/GJ ($0.26/million Btu) in US$1990. New design methods, such as pinch technology for heat exchanger networks in chemical plants, also offer both energy and capital savings in new plant designs. Pinch technology, for example, realizes average energy savings in new plant designs of 40 percent.[136]

IMPROVING THE EFFECTIVENESS OF MATERIAL USAGE

The energy required to deliver industrial goods and services can often be lessened by using existing material more effectively or by changing the types of materials used.

Smaller quantities of higher performance materials can often be substituted for larger quantities of lower performance materials. The tensile strength of steel was increased by four times between 1910 and 1980, for example, allowing large reductions in the quantity of steel required in any particular application.[137] Plastics are being substituted for metal in many auto body parts-reducing weight and improving fuel efficiency, reducing industrial energy use, and improving corrosion resistance and durability.[138]

Materials can be more extensively recycled. Significant amounts of energy can be saved by recycling steel, aluminum, glass, paper, and other materials (see table 4-28). Even greater savings may be possible if, rather than melting down and recasting the material, the material can be used in exactly the same form as before—for example, if glass bottles are of a standard size and shape and can be simply washed out and reused. On the other hand, the increasing mixture of different materials, such as the use of plastics in automobile bodies, complicates recycling efforts if recyclability is not designed in.[139]

Extensive recycling is already done in developing countries through both informal and formal markets. In West Africa, for example, artisans routinely melt

[135] Ibid.

[136] Canan Ozgen et. al., "Designing Heat-Exchanger Networks for Energy Savings in Chemical Plants,' *Energy, vol. 14, No. 12, 1989,* pp. 853-861.

[137] Economic Commission for Europe, *Evolution of the Specific Consumption of Steel* (New York, NY: United Nations, 1984).

[138] A detailed review of advanced materials is given in: U.S. Congress, office of Technology Assessment, *Advanced Materials by Design*, OTA-E-35 1 (Washington, DC: U.S. Government Printing Office, June 1988).

[139] These issues are being examined in a forthcoming report from the U.S. Congress, Office of Technology Assessment, *Materials Technology: Integrating Environmental Goals With Product Design.*

Table 4-28—Energy Intensity of Primary and Recycled Materials

	Primary GJ/mt	Recycled GJ/mt	Savings (percent)
Aluminum	242-277	9.9-18.7	92-96
Glass	17.8	12.3	31
Paper			
Newsprint	51.6	40.4	22
Printing paper	78.8	50.5	36
Tissue paper	79.7	34.3	
Liner board	16.8	42.2	(-151)
Plastic	NA	NA	92-98
Solvents	27.9	4.7	83
Steel[a]	18.1	7.6	58

NA = not available or not applicable; mt = metric tonne.
[a]See table 4-19.

SOURCE: U.S. Congress, Office of Technology Assessment, "Facing America's Trash: What Next For Municipal Solid Waste?" OTA-O-424 (Washington, DC: U.S. Government Printing Office), October 1989; Energetic, Inc., "Industry Profiles: Waste Utilization," U.S. Department of Energy, Office of Industrial Technologies, DE-AC01-87CE40762, December 1990.

down scrap aluminum and cast it into pots. In turn, aluminum pots perform much better than traditional fired clay pots for cooking. They provide significant energy savings due to their higher thermal conductivity and they rarely break--costing someone their supper. Improved (higher efficiency) biomass stoves (see ch. 3) are commonly made of recycled metal, culled from wrecked cars or oil drums. As the economies of developing countries grow, these informal recycling efforts may need additional incentives and/or capitalization to continue at a high level.

The quantity of energy intensive materials consumed can also be reduced by the use of energy efficient technologies. If energy is used efficiently, fewer power plants are needed. A typical coal-fried power plant might require 2,000 GJ (1,900 million Btu) of energy intensive construction materials per MW of capacity[140]--the equivalent of its entire power output for a month.[141] Similarly, if buses, light rail, or other systems substitute for automobiles, then both the cement needed to build the road and the steel needed to build the cars can be reduced per passenger-kilometer or freight-tonne-kilometer. Lightweight fuel efficient automobiles use less materials to construct and require fewer steel- and concrete-intensive refineries.

Quality control[142] can play an important role in saving energy by reducing the amount of scrap and reworking that is necessary. For example, in the early 1980s Ford Motor Co. rejected as much as 8 to 10 percent of the flat-rolled steel it obtained from U.S. producers such as Bethlehem Steel. This has since been lowered to 1 percent.[143] In India, modernization of the Rourkela steel plant is expected to raise the yield of liquid steel to steel slabs from 79 percent currently to 92.5 percent.[144] This alone will reduce energy consumption per unit of steel output by 17 percent.

Quality control is also important in assembling consumer goods. Factories that use outmoded methods of mass production (as opposed to lean production)--in which products are primarily inspected for defects after they are built—typically expend a quarter of

140 Jyoti K. Parikh, "Capital Goods for Energy Development: power Equipment fOr Developing Countries," *Annual Review of Energy*, vol. 11, 1986, pp. 417-450.

141 Note, for example, that the additional material in a refrigerator will not primarily be energy intensive steel+ xcept perhaps for a huger heat exchanger-but low density insulation with a correspondingly low energy-intensity. Thus the savings in materials by building fewer power plants are generally not offset by increases in material demands by the end-user.

142 Genichi Taguchi and Don Clausing, "Robust Quality," *Harvard Business Review*, vol. 68, No. 1, January-February 1990, pp. 65-75; Raghu N. Kackar, "Taguchi's Quality Philosophy: Analysis and Commentary," *Quality Progress*, December 1986, pp. 21-28; Thomas B. Barker, "Quality Engineering by Design: Taguchi's Philosophy," *Quality Progress*, December 1986, pp. 32-42; Daniel E. Whitney, "Manufacturing By Design," *Harvard Business Review*, vol. 66, No. 4, July-August 1988, pp. 83-91.

143 Energetics, Inc., op. cit., footnote 75; "Quality," *Business Week*, No. 3002, June 8, 1987, p. 131

144 Amit Chatterjee, op. cit., footnote 84.

their effort on finding and fixing mistakes in the assembled products. Thus, a quarter of the time and labor, and a similar share of the energy expended is not used to produce goods, but rather to rework goods that were not built correctly the first time.[145] Statistical process control and just-in-time (JIT) inventory control can dramatically reduce these losses.

JIT inventory control contributes to reducing inventories and the amount of material handling required in a plant. In a conventional mass production factory, large inventories are kept on hand to be used as needed by the assembly line. This requires large amounts of handling and storage space in order to store these components when they frost arrive at the assembly plant and to then retrieve them when needed by the assembly line. JIT eliminates this extra handling as well as reduces the need for expensive (and material intensive) storage areas. European automobile assembly plants, for example, keep 10 times as large an inventory of spare parts, more than 3 times the area for repairing defects in assembled cars, and one-third more total space per output than Japanese auto assembly plants that have fully adopted just-in-time assembly and other elements of ''lean' production.[146]

Similar savings from lean production have been achieved in many other industries, from air conditioners to microwave ovens. The resulting savings are substantial in terms of reduced inventory costs, plant capital costs, improved labor productivity, improved product quality, and as a bonus, reduced energy consumption. Such savings are particularly important where there is a shortage of working capital and interest rates are high.[147] Finally, quality in the form of improved product lifetimes can reduce the frequency with which the product must be replaced.

These improvements in manufacturing--statistical process control, just-in-time inventory control, etc.—are necessary if a country is to be competitive in world markets. Such techniques can also provide substantial energy savings.

BARRIERS TO ENERGY EFFICIENCY IMPROVEMENTS IN INDUSTRY

A number of factors limit the efficiency, productivity, and performance of industrial operations in developing countries. These are summarized in table 4-6 and a few selected cases are discussed below. Plant managers and others are often making substantial efforts to improve energy efficiency, but are laboring under highly adverse conditions. As examples, manufacturing plants are often too small to be optimally efficient; available technologies are often low quality or obsolete; national infrastructures are often inadequate; the plant may lack foreign exchange to purchase critical components not available locally; and there is generally a lack of skilled technicians, engineers, and managers.

Small Scale

Iron and steel plants, cement plants, paper mills, and other industrial operations in developing countries are often much smaller than those in the industrialized countries due to:

- smaller markets;
- poor transportation infrastructures that limit the cost effective distance for transport;
- reduced capital costs and associated risks;
- the benefits (in labor-rich developing countries) of often greater employment per unit output.

For example, the average U.S. paper mill has an annual capacity of approximately 100,000 tons; the average Latin American mill has a capacity of 18,000 tons; in Africa 9,000 tons, and in Asia (except Japan) 5,000 tons.[148] These small plants require significantly more energy per unit output because of scale effects. In addition, the small size of these industries increases the cost of installing more energy efficient equipment per unit energy saved. These small mills must also often meet the full range of products demanded in a developing country, while using relatively less production

[145]Otis Port, ''Quality,'' *Business Week*, No. 3002, June 8, 1987, p. 131.

[146]James P. Womack, Daniel T. Jones, and Daniel Roos, The *Machine That* Changed The *World* (New York, NY: MacMillan Publishing, 1990), p. 92.

[147]Note, however, that for JIT to work, reliable transportation and communications infrastructures are required.

[148]Andrew J. Ewing, op. cit., footnote 125, p. 45.

equipment with limited flexibility and with lower production runs per type of product.

National Infrastructures

Inadequate national infrastructures also reduce efficiency and productivity. Poor transport infrastructure, for example, reduces cost-effective transport distances and market sizes. Frequent electric power brownouts or cutoffs can seriously disrupt operations. The Indian steel minimill industry, for example, received just 38 percent of the power needed to run at full capacity between 1976 to 1986. In response, the steel, cement, and other industries have installed-at considerable expense—large amounts of onsite generation capacity. The Indian cement industry had installed some 545 MW of onsite capacity as of 1988-89. Overall, some 40 percent of electric power needs in India's cement industry are met with onsite generation, usually by low efficiency steam plants.[149]

Available Technology

Paper plants, for example, are often sold in developing countries as turnkey operations. Under these circumstances, one of the principal considerations is the initial capital cost. Oil freed boilers and generators are cheaper than waste wood or dual fuel boilers and/or cogeneration systems and so will usually be specified even though these oil-based systems will require very expensive fuel. Similarly, process control equipment may often be omitted in order to reduce capital costs, but then prevents monitoring and fine tuning plant processes.[150]

Financial Constraints

The additional capital cost to the end user of energy efficient equipment can be a substantial barrier to investment. Investment costs raise several different types of problems. The first is the 'disconnect" between the user and the utility: the total system capital cost is often lower for energy efficient equipment, but the capital savings accrue to the utility while the capital costs are incurred by the user. Similarly, there is often a ''discomect" between the purchaser and the user. Where equipment is leased, the capital costs go to the purchaser—who will minimize expenditures by purchasing less efficient equipment, while the higher energy bills go to the user.

Second, potential users of energy efficient equipment-even large industrial organizations-will often have an effective discount rate that is much higher than that justified by their cost of capital, let alone social discount rates. This can dramatically shorten the amount of time they are willing to wait for energy savings to pay for the higher initial capital cost of energy efficient equipment. There are several reasons for these high effective discount rates. Foremost among these is that energy is just one component of overall corporate strategy to improve profitability and competitiveness, and often a rather minor component at that. Energy must compete with these other factors of production when investment choices are made and when the scarce time of skilled manpower is allocated. In particular, capacity expansion provides a much more visible investment alternative and is usually the preferred choice.

In existing plants, a pool of capital may be budgeted for different types of plant improvements, such as better process equipment or for improved energy efficiency. Different energy efficiency improvements then compete against each other for this limited budget rather than against an overall level of profitability. Energy efficiency projects with very high potential returns-but not the highest—may then be deferred.[151] In other cases, energy/cost savings above a certain-very high-threshold level may be required before management considers it worthwhile diverting the attention of their limited technical manpower from the business of keeping the factory running.

Investments in new plant and equipment may also focus on less efficient equipment than is desirable from a systemwide life cycle cost perspective. Factors that constrain these investments in developing countries include:

- aversion to the risk of relatively new, untested equipment, and the lack of an adequate infrastructure to repair the equipment should it fail;
- lack of technical manpower to install, operate, or maintain state-of-the-art equipment;
- the risk of currency exchange rate fluctuations when purchasing equipment denominated by

[149] Energy and Environmental Analysis, Inc., Op. Cit., footnote 86.

[150] Andrew J. Ewing, op. cit., footnote125.

[151] Marc Ross, "Capital Budgeting Practices of Twelve Large Manufacturers, " *Financial Management,* winter 1986, pp. 15-21.

foreign exchange loans; and
- the risk of political instability and consequent uncertainty in mid- to long-range loans.

Third, in many developing countries, fuel and electricity costs are highly subsidized so that investments in energy efficient equipment by the industrial user have very long payback times. For example, a recent review of 60 developing countries found the average cost of electricity to be $0.043/kWh (US$1990) while the average cost (including industrial, commercial, and residential users) of new supply was about $0.08/kWh.[152]

In addition, some countries use cost-plus pricing for key public sector dominated industries—allowing the industry to directly pass on the cost of energy and providing no incentive to conserve. India, for example, long used cost-plus pricing in their public sector industries. They have now largely eliminated this pricing system in cement, aluminum, and pulp and paper, and have modified this system in the iron and steel and in the fertilizer sectors in order to spur energy efficiency improvements. Cost-plus pricing remains in effect, however, in the Indian refinery sector.[153]

Fourth, the lack of foreign exchange to buy spare parts can also be a serious handicap. This has been an important factor in the decline of the Tanzanian cement industry, which operated at just 22 percent of rated capacity in 1984.[154]

Fifth, secondhand markets for equipment may provide no premium for efficient equipment, while at the same timekeeping large amounts of inefficient equipment in operation, sometimes as ''hand-me-downs' from industrial countries.

POLICY RESPONSES

There are a variety of possible policy responses to these barriers to energy efficiency improvements. These policy responses are summarized in table 4-7 and a few of these are discussed below.

In making their choice of industrial equipment, manufacturers must consider much more than energy efficiency. Decision criteria include: the financial return, the quality and quantity of product produced, the timeliness and reliability of the production equipment, and the flexibility of the equipment, among others.

Simply investing in high technology mills, as currently configured, does not necessarily meet these criteria. High technology mills can achieve higher efficiencies, but also tend to have high capacity-making them less suited to developing countries with their lower volume markets. High technology mills are expensive to maintain, require scarce technical manpower, and spares are often unavailable due to the lack of foreign exchange, lengthy licensing procedures, and high import duties. High technology mills may also not provide, for a variety of reasons, the savings desired. Continuous casting in the Chinese steel industry, for example, has so far provided energy savings at a cost several times greater than the price of the energy supply due to the mismatch between the product the continuous casters were designed to provide and that which was required.[155] Finally, high technology mills provide less employment—widely seen as a liability in developing countries with their large labor pools.[156]

Information

Even large industries may lack information on the opportunities for and potential savings of investing in energy efficient equipment. Policy responses might include information programs-particularly in conjunction with regional energy efficiency testing centers, labeling equipment with its energy consumption, training programs, and energy audits of industrial operations by groups established in-house or by outside experts-possibly supported by the government, utilities, or even private Energy Service Companies.

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152 A. Mashayekhi, World Bank, Industry and Energy Department, *Review of Electricity Tariffs in Developing Countries During the 1980s*, Industry and Energy Department Working Paper, Energy Series Paper No. 32 (Washington DC: World Bank, November 1990).

153 Ahmad Faruqui et. al., "Application of Demand-Side Management (DSM) to Relieve Electricity Shortages in India, ' contractor report prepared for the Office of Technology Assessment, April 1990.

154 D.F. Stewart and B. Muhegi, op. cit., foonote 118.

155 Mark D. Levine and Li, Xueyi, U.S. Department of Energy, Lawrence Berkeley Laboratory, *Energy Conservation Programs in (he Peoples Republic of China*, Report No. LBL-29211 (Berkeley, CA: Lawrence Berkeley Laboratory, August, 1990).

156 Vinod Bihari, ''Problems and Solutions in Adopting Modern Technology At Steel Plants in Developing Countries," *Iron and Steel Engineer*, February 1988, pp. 26-31.

Energy audit services, when combined with a variety of supporting conditions including information, training, financial assistance, appropriate price incentives, and others, can be highly successful. In a USAID program in Kenya, for example, just 24 audits and 30 site visits, together with other supporting activities, resulted in annual savings of about US$1.1 million, at a cost of $136,000 annually in the pilot program.[157] Nonetheless, the types of efficiency improvements adopted in this program were limited to short to medium term pay-back measures, were primarily implemented with in-house staff, and were usually realized with very low cost used equipment or equipment made onsite or otherwise locally available. Very seldom were firms willing to borrow for these investments; most were financed out of maintenance budgets and internal funds.

Numerous countries now have audit programs,[158] but the degree of their effectiveness depends on the effort invested, the extensiveness of related support programs such as training and financial assistance, and other factors.

Numerous counties also have training or other informational programs. South Korea, for example, provided training sessions to some 89,000 people between 1974 and 1980 through their national energy management association.

Additionally, it might also be useful in many cases to establish uniform testing methodologies (test standards) to measure the performance of motors, ASDs, pumps, fans, and other equipment on a uniform basis. Such tests might best be done at regional centers with close institutional relationships to industrial country institutions.[159] Such a regional center might also play a role in concentrating a critical mass of manpower on key RD&D issues; developing computer design or diagnostic tools; establishing methodologies for field evaluation and extension teams; developing protocols for interfacing different types of efficient equipment—such as common forms of communication to control equipment via power line carriers or other means to allow utility load management; and others.

Availability

Where potential users are aware of the advantages of energy efficient equipment, they may still not be able to obtain it. Obstacles may range from an insufficient local market to be worth the expense for the vendor to develop it; lack of sufficient maintenance infrastructure to support use of the equipment; taxes and tariffs that prevent the import of the equipment even when its use would provide substantial capital and/or foreign exchange savings; and other factors.

Policy responses include local development of technologies, organizing local or regional buyers markets to develop sufficient demand to allow development of the market, providing special incentives to make the vendor's effort to enter a small market more attractive, relaxing taxes and tariffs on energy efficient equipment, and others. Local development efforts include the PROCEL (see ch. 3) program of Brazil, which has supported the development of more efficient refrigerators, water heaters, air conditioners, motors and controls, and lighting technologies.

Minimum efficiency standards have been set, for example, by Taiwan for numerous consumer appliances. Window air conditioners have improved in efficiency by over 40 percent since the standards were established. Building efficiency standards have been established in Singapore, South Korea, China, and on a voluntary basis are being established for Indonesia, the Philippines, and Thailand.[160] On the other hand, there are sometimes sound technical reasons for not mandating minimum efficiency standards for a product. Electric motors, for example, are more susceptible to stalling and burning out as their efficiency is increased if there are voltage fluctuations or if they are driving loads with very large starting torques. Mandating minimum efficiency for all (as opposed to certain types) industrial

157 H. Mike Jones, "Kenya Renewable Energy Development Project: Energy Conservation and Planning, Final Report," contractor report prepared for the U.S. Agency for International Development, June 28, 1985.

158 These include: Argentina, Bangladesh, Brazil, Costa Rica, Ecuador, Egypt, El Salvador, Ghana, Guatemala, Honduras, India, Indonesia, Jordan, Korea, Morocco, Pakistan, Panama, Philippines, Sri Lanka, Thailand, and Tunisia. Steven Nadel, Howard Geller, and Marc Ledbetter, "A Review of Electricity Conservation Programs for Developing Countries," draft report for the American Council for an Energy Efficiency Economy, Washington DC, Jan. 1991; Amory Lovins, Director, Rocky Mountain Institute, personal communication, July 2, 1991.

159 These might include the National Institute for Standards and Technology, Environmental Protection Agency (for environment-related technologies), the American National Standards Institute, the Institute for Electrical and Electronics Engineers, and others.

I@ Steven Nadel, Howard Geller, and Marc Ledbetter, Op. cit., footnote 158.

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Table 4-29-Commercial Energy Use in Agricultural Production, 1972/73

	Share				
	Fertilizers	Traction	Irrigation	Pesticides	Total
Industrial countries	35%	62%	1%	2%	107 Mtoe[a]
Developing countries	68%	22%	8%	2%	31 Mtoe

[a]Mtoe = million tons of oil equivalent.

SOURCE: "Agricultural Mechanization in Development: Guidelines for Strategy Formulation" (Rome, Italy: Food and Agriculture Organization of the United Nations, Agricultural Services Bulletin, No. 45, 1984).

motors might then sometimes lead to undesirable results if the motor were incorrectly specified.

In some cases, more efficient equipment may be available, but will not be considered for developing country applications due to its greater complexity and more difficult operation and maintenance. For example, high pressure steam boilers are widely available, but require more sophisticated water treatment-without which they can fail, and require substantial skills if they are to be operated safely.

Capital Cost

A variety of responses have been developed to the capital constraint problem. These include: loan programs, rebates, tax credits, accelerated depreciation, or other financial assistance for efficient equipment; adjusting energy prices to reflect its full cost; direct installation of efficient equipment by the utility; alternative financing arrangements in order to eliminate the "disconnect" between the user and the utility or between the user and the owner; and other arrangements.

A number of rate incentive programs (adjusting electricity tariff rates in order to reduce peak loads, base loads, etc.) have been established in Brazil, Costa Rica, Indonesia, Pakistan, Uruguay, and other countries. Loans, grants, leasing arrangements, tax credits, and other financing schemes are being tried in Thailand, Brazil, China, India, and elsewhere.[161]

A broader range of barriers to investment in energy efficient technologies is given in table 4-6; a list of potential policy options is given in table 4-7. These are not directly matched up as many barriers have multiple policy responses and, correspondingly, many policy options address a variety of barriers. These barriers and policy responses are strongly influenced by the scale and type-small traditional to large modern-of the industry concerned.

AGRICULTURE

Relatively little energy is used directly in the agricultural sector, ranging from less than 1 percent of the national total in the United States to perhaps 5 to 8 percent of the national totals in developing countries such as Brazil, China, India, and Kenya (see tables 4-3, 4-29). Energy used to manufacture farm equipment and fertilizer, store and process food, or haul it to market are generally accounted for separately by these energy balances in the industrial, commercial, and transport sectors. Despite its relatively low energy use, agriculture is nevertheless a very important sector in the developing countries due to its social and economic significance: agriculture provides fully one-third of the Gross Domestic Product for the nearly 3 billion people in low income countries and it provides an even higher share of national employment (see figure 4-13).[162] In sub-Saharan Africa, for example, 75 percent of the work force is engaged in agriculture, compared to just 2 percent in the United States. Other comparisons of agriculture between developing and industrial countries are given in tables 4-30 and 4-31. Agriculture is also important in terms of its impact on the local, regional, and global environment.[163]

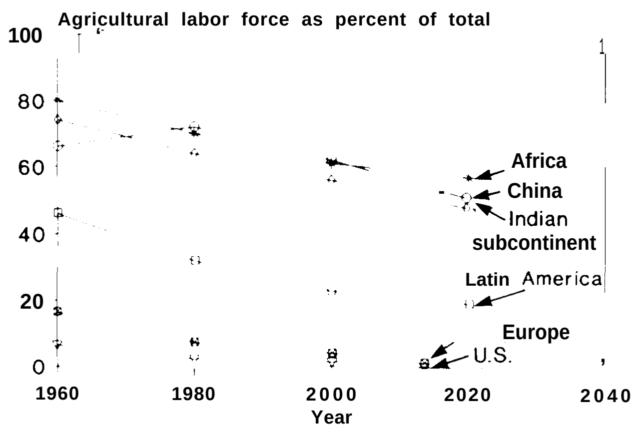
As for the residential, commercial, and industrial sectors, there are numerous opportunities for improving the efficiency of energy use in agriculture. These include improvements:

[161] Steven Nadel, Howard Geller, and Marc Ledbetter, op. cit., footnote 158.

[162] World Bank, *World Development Report 1990* (New York, NY: Oxford University Press, 1990).

[163] A more detailed discussion of these issues can be found in: U.S. Congress, Office of Technology Assessment *Energy in Developing Countries*, OTA-E-486 (Washington DC: U.S. Government Printing Office, January 1991).

Figure 4-13—Agricultural Labor Force as a Percent of The Total Labor Force, 1960 to 2020



The developing countries have large shares of their total labor force in agriculture.

SOURCE: World Bank, ***Agricultural Mechanization: Issues and Options*** **(Washington, DC: World Bank, 1987).**

Photo credit: Appropriate Technologies, International

More efficient irrigation technologies could save energy and boost agricultural productivity.

- in the industrial energy used to produce farm implements, fertilizers and other chemicals (discussed above);
- in the application and utilization by the plants of fertilizers and other chemicals;
- in the pumping and application of irrigation water;
- in the efficiency of traction for cultivation, sowing, weeding, harvesting, and other operations as well as potentially minimizing the need for traction through low-tillage agriculture;
- in the efficiency of post-harvest crop drying (using solar energy or heat recovery systems) and storage (see commercial refrigeration, ch. 3);
- in the utilization of crop residues for energy production (see ch. 6); and
- in the transport of crops to market (see ch. 5), among others.

The discussion here focuses primarily on efficiency improvements in the use of commercial energy for irrigation and traction in developing countries. Improvements in the production of fertilizer were discussed above and transport is discussed in chapter 5. Discussion of agricultural practices, programs, or policies more generally are beyond the scope of this assessment (see box 4-A);[164] several recent Office of Technology Assessment publications examine these and related issues.[165]

Irrigation

Irrigation frees the farmer from dependence on irregular rains and raises yields, allowing double- and even triple-cropping. Some 160 million hectares of land in developing countries are irrigated. In Asia, 100 million hectares are irrigated, and this land produces roughly 60 percent of the region's food on just 45 percent of its cropped area.[166]

India, for example, nearly doubled its irrigated area between 1950 and 1984 in order to reduce its

[164] For a recent review, see Ramesh Bhatia and Rishi Sharma, "Energy and Agriculture: A Review)' Ashok V. Desai (cd.), *Patterns of Energy Use in Developing Countries* (New Delhi, India: Wiley Eastern Limited, and Ottawa, Canada: International Development Research Center, and Tokyo: United Nations University, 1990).

[165] U.S. Congress, Office of Technology Assessment, *Enhancing Agriculture in Africa: A Role for U.S. Development Assistance,* OTA-F-356 (September 1988); U.S. Congress, Office of Technology Assessment, *Grassroots Development: The African Development Foundation,* OTA-F-378 (June 1988); U.S. Congress, Office of Technology Assessment, *Technologies to Sustain Tropical Forest Resources,* OTA-F-214 (March 1984); U.S. Congress, Office of Technology Assessment, *Technologies to Maintain Biological Diversity,* OTA-F-330 (March 1987). See also the UNFAO and World Bank publications listed below,

[166] Montague Yudelman, "Sustainable and Equitable Development in Irrigated Environments,' Jeffrey Leonard (cd.), *Environment and the Poor: Development Strategies for a Common Agenda* (New Brunswick, NJ: Transaction Books, 1989), pp. 61-85.

Table 4-30-Comparison of Agriculture in Developing and Industrial Countries, 1980

	Developing	industrial
Share of world population	67%	33%
Share of world agricultural production	38%	620/o
Production per agricultural worker	$550 (1975$)	$5,200
Arable land per agricultural worker	1.3 ha	8.9 ha
Fertilizer use (kg/ha) of agricultural land	9 kg/ha	40 kg/ha
Total daily food consumption	2,200	3,300
(low-Income)	2,000	NA
(middle-Income)	2,500	NA
Number of seriously malnourished	435 Million	NA

NA - Not available or not applicable.

SOURCE: "Agriculture: Toward 2000" (Rome, Italy: Food and Agriculture Organization of the United Nations, 1981),

Table 4-31-Agricultural Indicators for Various Developing and Industrial Countries, 1982/83

Country	Agricultural labor percent of total	Arable land Ha/capital	Fertilizer kg arable land	Rice yield kg paddy/ha
India	61	0.24	39	2,200
Bangladesh	83	0.10	60	2,050
China	57	0.10	181	5,070
Pakistan	52	0.22	59	NA
Sri Lanka	52	0.14	71	NA
Burma	50	0.27	17	3,090
Egypt	49	0.06	361	NA
Philippines	44	0.23	32	2,470
Brazil	36	0.58	37	NA
Iran	36	0.34	66	NA
Korea	35	0.05	345	NA
Mexico	34	0.32	61	NA
Italy	10	0.22	169	NA
Japan	9	0.04	437	5,700
France	8	0.34	312	NA
Canada	4	1.87	49	NA
Germany	3	0.12	421	NA
United Kingdom	2	0.12	375	NA
U.S	2	0.82	105	5,150

SOURCE: *TERI Energy Data Directory and Yearbook, 1988* (New Delhi, India: Tata Energy Research Institute, 1989).

vulnerability to poor monsoons.[167] More than 6 million electric and 3 million diesel pump sets have been deployed (see figure 4-14). Electric pumpsets consumed some 23,000 GWh of electricity in India in 1985-86, about 14 percent of total national electricity generation[168] and about two-thirds of rural electricity use.[169] Similarly,in China, irrigation consumes unestimated 70 percent of rural electricity, with the remainder used for food processing, various rural industries, and lighting.[170]

Failure to provide adequate power for pumping can have serious consequences for those regions dependent on it. The Sudanese lost some $100 million worth of agricultura1 output in 1984 due to a shortage of energy for pumping and traction. Similarly, the Somalis lost 40 to 60 percent of their irrigated crops in some regions during 1984 due to a lack of diesel fuel for irrigation.[171]

Irrigation is most commonly done with either electric motor or diesel driven pumps. Electric

167Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988* (New Delhi, India: Tata Energy Research Institute, 1990), p. 128.

168Ashok Desai, "Energy Balances for India, 1985 -86,' contractor report prepared for the Office of Technology Assessment, 1990. This is equivalent to 125,000 GJ.

169S. Ramesh and T.V. Natarajan, "Policy Options in Rural Electrification in India,' *Pacific and Asian Journal of Energy,* vol. 1, 1987, pp. 44-53.

170C. Howe, *China's* Economy (New York, NY: Basic Books, Inc., 1978), p. 88.

171U.S. Congress, House Select Committee on Hunger, *Hearings on Energy and Development: Choices in the Food Sector, Serial No.* 101-11, U.S. Government Printing Office, July 25, 1989.

Box 4-A—Agricultural Energy Use in Context

A thorough discussion of agricultural energy use necessarily includes a host of important issues beyond the scope of this study. Other issues of importance in agriculture, but not discussed here, include:

- proper pricing of agricultural products (allowing the market to work);
- the international impact of agricultural subsidies by Europe, Japan, and the United States, particularly on domestic valuations of crops, land tenure, and subsistence agriculture in developing countries;
- soil conservation and the proper accounting for the value of soil and other environmental assets;[1]
- the agricultural potential of low-energy inputs such as microcatchments, improved pest management, intercropping and agroforestry, and improved post-harvest storage;
- the role of higher value inputs (including information-intensive management as for improved pest management or intercropping, etc.) into agriculture to reduce agricultural expansion onto biologically rich or fragile lands and the corresponding environmental damage that can then result; and
- the multiple roles and needs served by traditional technologies--draft animals can provide meat, leather, and dung in addition to traction, and cows also provide milk and reproduce while modem electric or engine-driven mechanical drive only provides traction.

In the 1950s, most Western development economists did not view the agricultural sector as important for economic development.[2] Today, the view has been largely reversed, with agriculture widely seen as an important underpinning of an economy and some suggesting that, under certain conditions, agriculture could be an important driver of industrialization just as export markets have been for the newly industrialized countries.[3] Realizing this potential will require public sector support and substantial extension services due to the highly dispersed nature and small scale of agriculture.

1 Rattan Lal, "Managing the Soils of Sub-Saharan Africa," Science, vol. 236, May 1987, pp. 1069-1076.

2 John M. Staatz and Carl K. Eicher, "Agricultural Development Ideas unhistorical Perspective," Carl K. Eicherand John M. Staatz (eds.), *Agricultural Development in the Third World* (Baltimore, MD: Johns Hopkins University Press, 1984) pp. 3-32.

3 Irma Adelman, "Beyond Export-Led Growth," *World Development*, vol. 12, No. 9, 1984, pp. 937-949; John W. Mellor, "Agriculture on the Road to Industrialization' John P. Lewis and Valeriana Kallab (eds.), *Development Strategies Reconsidered, Overseas* Development Council (New Brunswick, NJ: Transaction Books, 1986) pp. 67-90,

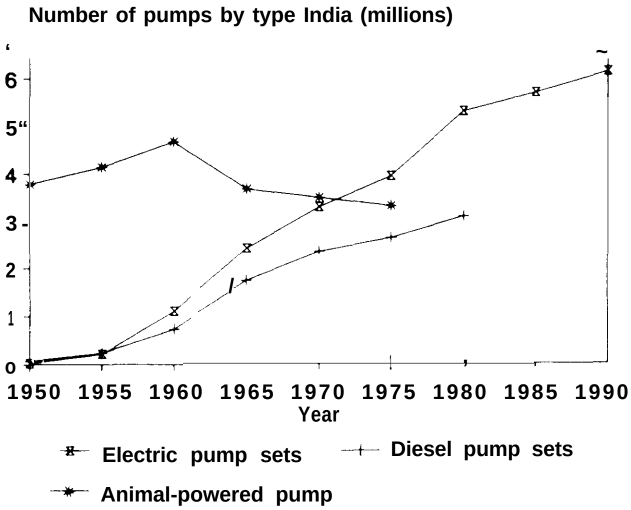
pumps are quite reliable (although subject to interruptions in the electric power grid) and convenient, and are often the lowest cost alternative. Diesel-electric pumping systems, in which diesel generators produce electricity that is then used to drive electric pumps, and direct diesel and gasoline-powered pumps are more often used where no electric grid is available. These are much less mechanically dependable than electric pumps. Other pumping systems include wind energy, photovoltaics, producer gas driven engines, and others. Only grid connected electric pumping will be examined here; other systems are explored in chapter 6.

As indicated above, numerous improvements are possible in pumping systems with potentially vex-y large leverage on upstream utility investment. A field study in India found 90 percent of the agricultural pumps could be substantially upgraded. For example, reducing the friction in the piping system and foot valve in a field test of 25,000 pumps typically cost about $80, but provided energy savings of 30 percent for the same quantity of water pumped. Assuming 5 kW input motor/pump systems operating at an annual capacity of 10 percent,[172] this $80 investment in motor/pump system efficiency provides a $570 savings in utility capital investment (total, not annualized). Similarly, a field trial of 300 complete rectifications of pumping systems resulted in 50-percent energy savings or 10,600 kWh/year per pumping system. This is equivalent to 1.21 kW of firm capacity with an avoided cost of roughly $4,600 per pumping system (total, not annualized). In contrast, the investment per pumping system was about $600.[173] At a cost of $0.09/kWh, these

172 These are nominal values as reported for more carefully documented field trials discussed by S.M. Patel, "Low-Cost and Quick-Yielding Measures for Energy Conservation in Agricultural Pumps," *Pacific and Asian Journal of Energy,* vol. 2, No, 1, 1988, pp. 3-11. and by S, Ramesh and T.V. Natarajan, "Policy Options in Rural Electrification in India," *Pacific and Asian Journal of Energy,* vol. 1, No. 1, 1987, pp. 44-53.

173 S.M. Patel, "Low-Cost and Quick-Yielding Measures for Energy Conservation in Agricultural Pumps," *Pacific and Asian Journal of Energy, vol. 2, No.* 1, 1988, pp. 3-11.

Figure 4-14-Use of Agricultural Pumpsets in India, 1950 to 1990



SOURCE: Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY), 1988* (New Delhi, India: 1989).

investments would have a payback time of about 4 months. The electricity price paid by farmers, however, is substantially lower in India due to subsidies, with correspondingly longer payback times.

Similar efficiency improvements are possible elsewhere in the world. In the United States, for example, average agricultural pump efficiencies have been estimated at 55 percent, with the potential to increase them to an average of 82 percent.[174]

Other measures that could have a substantial impact on energy use for agricultural pumping include better techniques for delivering the water to the plant-such as drip irrigation, the use of sensors to monitor the actual need for water by plants, or the use of computer controls for scheduling irrigation.[175]

Traction

Many countries have made greater use of animal or mechanical traction for agricultural operations to ease seasonal labor demands. In Africa, the emphasis has been primarily on animal traction due to the frequent failure, for a variety of technical and institutional reasons, of projects attempting to introduce tractors.[176] Draft animals become increasingly difficult to support as pasture is converted to crops in the most densely populated regions, however, and feeding the animal over the course of a year can require the output of several times as much land as the animal can work during the short growing season.

Energy use (crop residues) for draft animals is not currently included in national energy balances, despite its important role.[177] If it were, the energy input into agriculture in some developing countries would increase dramatically. For example, it has been estimated that the energy use in animal traction in India during 1970/71 ranged from about 1 to 5 times greater (depending on assumptions and methodology) than commercial energy inputs into agriculture.[178] A variety of improvements in nutrition, harness design, and other factors can greatly improve the work output by draft animals.[179]

Mechanical traction comes in many forms, ranging from power tillers to large tractors. Large scale manufacturing and engineering innovations have also made many of these systems increasingly accessible to small farmers.[180] There is a wide variation between countries in the extent to which agriculture is mechanized (see figure 4- 15). There is a similarly wide and inverse variation in the number of agricultural laborers (see figure 4-16).

In China the most popular tractor is probably the ''Worker-Peasant,' a 7-hp garden tractor. In Thai-

[174] Joseph T. Hamrick, ''Efficiency Improvements in Irrigation Well Pumps,'' *Agricultural Energy: Volume 2, Biomass Energy Crop Production,* selected papers and abstracts from the 1980 American Society of Agricultural Engineers (St. Joseph, MI: American Society of Agricultural Engineers, 1981).

[175] Energetics, Inc., for the U.S. Department of Energy, Office of Industrial Technologies, "Industry Profiles: Agriculture," Contractor No. DE-AC01-87CE40762, December 1990.

[176] Hans P. Binswanger et. al., *Agricultural Mechanization: Issues and Options* (Washington, DC: World Bank, 1987).

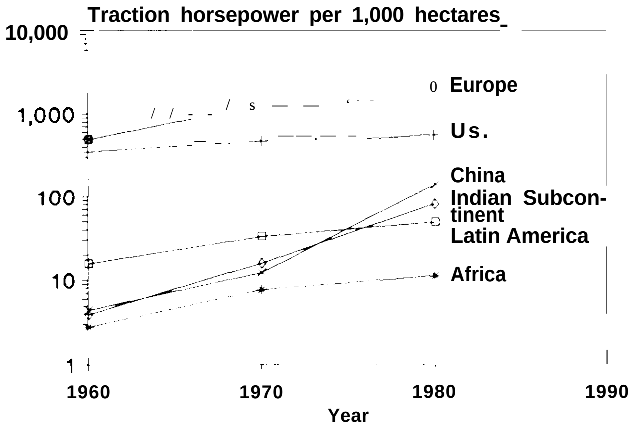
[177] Arjun Makhijani, "Draft Power in South Asia Foodgrain Production: Analysis of the Problem and Suggestions for Policy," contractor report prepared for the Office of Technology Assessment, June 1990.

[178] Ramesh Bhatia, "Energy and Agriculture in Developing Countries," *Energy Policy,* vol. 13, No. 4, August, 1985, pp. 330-334.

[179] See, for e-pie, Peter Munzinger, *Animal Traction in Africa* (Germany: Eschborn, 1982); Jane Bartlett and David Gibbon, *Animal Draught Technology: An Annotated Bibliography* (London: Intermediate Technology Publications, 1984). More recent and complete information can be obtained from: Tillers International, Kalamazoo, Michigan or from the Centre for Tropical Veterinary Medicine, University of Edinburgh, Scotland.

[180] Hans p. Binswanger et. al., op. cit., footnote 176.

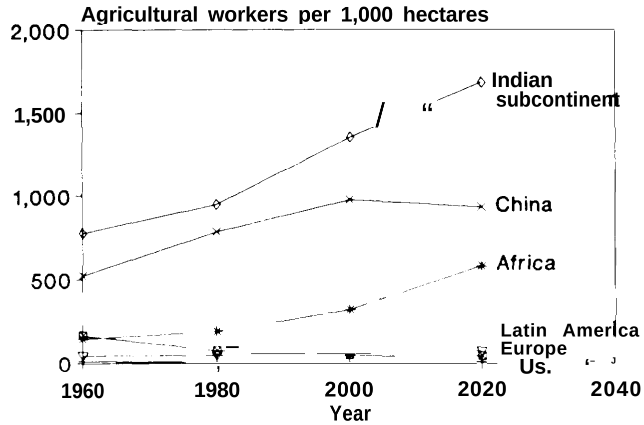
Figure 4-15—Mechanical Traction Per 1,000 Hectares of Agricultural Land



The developing countries have much lower levels of agricultural mechanization than the industrial countries.
Note the logarithmic scale.

SOURCE: World Bank, *Agricultural Mechanization: Issues and Options* (Washington, DC: World Bank, 1987).

Figure 4-1 6—Agricultural Workers Per 1,000 Hectares of Agricultural Land



SOURCE: World Bank, *Agricultural Mechanization: Issues and Options* (Washington, DC: World Bank, 1987).

land, a versatile system known as the 'iron buffalo' is widely used. This 8-hp system can alternately be used to plow (using 1 meter iron paddle wheels that are more stable in a paddy than rubber tires), pump water, power a cart, run a generator, or do other tasks. These iron buffaloes allow farmers to drain their rice fields, mechanically or hand-scatter the seeds and, when the rice sprouts, pump water back into the paddies. This avoids the traditional laborious hand planting of seedlings in the rice paddies. By 1984, some 400,000 of these systems were in use in Thailand. *81 In contrast to these smaller tractors, the most popular tractor in India, where the number of tractors almost doubled from 1972 to 1977,[182] is a 30-hp diesel.

Energy use by mechanical traction equipment varies widely by region and according to operating conditions and a host of other factors such as the degree to which the operation is power- or control-intensive. Some regions of Latin America are as mechanized as the industrial countries, while most African workers still rely primarily on hand tools.

Generally, diesel powered equipment is roughly 25-percent more efficient than gasoline powered equipment. Specific performance improvements in motors (for transport applications) are examined in detail in chapter 5. Mechanization of agriculture is one of several means of improving productivity; mechanization is not an end in itself.[183]

CONCLUSION

Industrial and agricultural energy use will continue to grow in developing countries in order to meet the aspirations of a growing population that is making the transition from a traditional rural to a modern urban lifestyle. Technologies either exist or can be readily adapted to substantially moderate these increased demands for industrial and agricultural energy use while still providing the energy services-manufactured goods and high quality foods-desired. These technologies can provide these energy savings at both a capital and an operating cost less than what is paid today. These savings can bean important source of capital to meet other pressing development needs and to spur more rapid economic development.

181 Ben Barber, "Buffaloes Mooove With the Times," *Asian Wall Street Journal,* July 24-25, 1987.

182 Tata Energy Research Institute, *TERI Energy Data Directory and Yearbook (TEDDY) 1988* (New Delhi, India: Tata Energy Research Institute, 1990), p. 137.

183 Hans p. Binswanger et. al., op. cit., footnote 176.