Sweden Beyond Oil: The Efficient Use of Energy

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Summary. Technology now being introduced in industry, buildings, and transportation is much more energy-efficient than today's average technology. Changes in production and consumption are tending to decrease the intensity of energy use. By applying available economic technology, it may be possible to reduce energy use in Sweden from the present 1400 petajoules per year to about 900 petajoules per year soon after the turn of the century, even with a 50 percent increase in the consumption of goods and services. Technology now being developed could reduce energy demand even further.

In previous studies (*1*, *2*) we addressed the choice of new energy supply systems as a replacement for oil in Sweden. Our objective here is to analyze the combined impact on future energy use of the increases in energy prices during the 1970's, of technological development, and of structural changes in the economy (*3*). Since the future development of society is partly based on values, we have tried to separate these values from the technical and economic analysis in creating options for the long-term development of energy demand. The approach and many of the observations and results are, we believe, applicable to other industrialized countries.

Causes of the Growth in Energy Use

Between 1950 and 1979 the use of energy in Sweden increased by a factor of almost 3. The increase is attributable to changes in population, industrial activity, transportation, and housing and building design (Fig. 1).

Population. In the 1950–1979 interval the Swedish population increased 18 percent. Population is expected to remain constant or to decline slowly during the next several decades.

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Industrial activity. Three-quarters of the increase in industrial energy use was due to the pulp and paper industry and the steel industry. Both industries now face major constraints. The total annual increment in Swedish forests of coniferous roundwood, the traditional raw material for paper production in Sweden, is largely committed to the pulp and timber industries. In the future, one might consider short-rotation plantations for raw material. In order to compete on the world market, paper and pulp based on short-rotation plantations and other deciduous wood would require such low wood prices in Sweden that its use for biomass fuel would be very competitive. Because of this, production of pulp can be expected to increase marginally or not at all.

The steel industry in Sweden faces considerable competition on the world market; it will probably not be able to expand production and may even have difficulties in maintaining the current production volume. In both industries there may, of course, be a shift toward products of higher value added. These constraints bode a shift in future industry toward less energy-intensive forms of production, such as engineering and chemistry (*4*). Compared to basic metals industries, engineering requires 14 times less energy per employee and 20 times less energy per dollar contributed to the gross domestic product (*3*).

In the emerging postindustrial society, consumption is shifting toward services and less material-intensive products (Fig. 2), such as computers, robots, advanced electronics, and medical equipment (*3*). This change is important, since a large part of industry's demand for energy is directly related to the amount of materials produced.

Transportation. Automobile transport increased by a factor of 7 to 8 between 1950 and 1979 and now accounts for about 60 percent of energy use in the transportation sector. Specific fuel demand increased little between 1950 and 1979, and the distance driven per vehicle was constant. This means that the increase in total fuel consumption was primarily due to an increase in the number of vehicles. The number of vehicles in the future will, of course, be related to economic development and population size, but there are now indications of saturation in the number of automobiles per capita.

Buildings. More than one-third of Sweden's energy is used for space heating. Since 1955 there has been a threefold increase in the use of energy for this purpose because of more and larger dwellings and the desire for higher indoor temperatures. The number of dwellings is related to population and household size. Households are already relatively small in Sweden (there are 2.4 persons per household), and this situation is unlikely to change much. The size of dwellings, however, is more directly related to overall economic development and the relative cost of houses.

In summary, many major factors that spurred the growth in energy use during the past 30 years are unlikely to continue to do so.

Effects of Energy Prices

In Sweden consumer oil prices, in constant dollars, declined by a factor of 2 between the mid-1950's and the early 1970's and then tripled between the early 1970's and the early 1980's. Sweden has no domestic oil, gas, or coal, and imported oil accounts for more than half of the country's gross supply of energy. Because of the rapid price increases, the energy system is now far from an economic optimum. Electricity prices also declined until the early 1970's. During the 1970's they increased in real terms by about 20 percent as more nuclear power was used. About 60 percent of electricity production, however, is still based on hydropower. The price increases have led to the development of technical equipment that is much more energy-efficient than that in general use today.

Conservation and Technological Progress

Energy conservation is often regarded as the modification of existing installations. However, the most important mechanism that leads to more efficient use of energy in industry is process change, that is, the use of new technology to provide the same products or services. Comparatively small improvements in energy efficiency may be obtained through backfitting in existing industry. Examples of the impact of process change include the development of new processes for nitrogen fixation that reduced specific energy demand fivefold between 1900 and 1960 (*2*) and new lighting technology that improved energy efficiency by a factor of almost 100 during this century (*5*).

Technological progress often leads to more substantial effects on productivity than substitution of capital for other factors of production. Almost 90 percent of the doubled labor productivity in the United States from 1909 to 1949 is explained by technological progress (*6*). New inventions to reduce the cost of one production factor also tend to reduce the requirement for all other factors of production (*7*).

Since World War II, both average labor and energy demand per unit of industrial output in Sweden have fallen without increasing the requirement for capital. This occurred in spite of a reduction in energy prices (*3, 8*).

Methodology

Our analysis of future energy demand is made in three steps. First, we identify structural changes that could affect future energy demand. Second, we examine what might happen if energy-efficient end-use technology becomes widely used. And third, we discuss when such technology might be in common use. This approach facilitates the identification of factors with potential impact on energy demand, that is, the potential of new technology is separated from its rate of introduction. The latter also depends on overall economic development and government policy.

The volume of activity was treated as an exogenous variable. Private and public consumption were converted to demand for industrial and public goods and services through a consumer goods matrix (*9*). An input-output model of the Swedish economy was used to associate a mix of private and public consumption with output from 24 production sectors (*10*). The model was extended to cover the total economy, including investments and foreign trade.

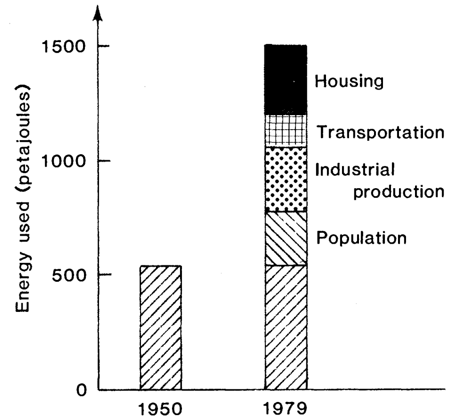

Fig. 1. Major components in the increase of energy use in Sweden, 1950 to 1979. The increases in industry, transportation, and housing are per capita.

To analyze the significance of new technology, we identified two sets of specific energy demand numbers. One set refers to presently known best technology that is or is judged to be economic and would thus be used if an economically optimum investment were made today (*11*). (This is best technology in an economic sense; greater energy reduction can always be achieved at extra cost.) The other set of demand numbers refers to technology still being developed. We call it advanced technology. It, too, does not represent a technological limit but is, in our judgment, in a cost bracket of interest.

The total energy demand was calculated at a future time when the economy has grown to different levels and when either of the two levels of energy efficiency numbers represents average intensity. The specific energy demand numbers are expressed in joules per dollar. Hence, for the industrial sector we have joules per dollar = (joules per kilogram) × (kilograms per dollar)

The first factor on the right-hand side represents the energy demand per physical unit of production. It is the typical result of energy analysis of industrial processes. The second factor reflects the value of production, that is, the number of kilograms of a product that can be bought for \$1. Of course, technically advanced products are much more expensive per kilogram than less advanced products. We allowed for some decrease in the number of kilograms per dollar in the engineering industry (*4*), but kept this number at the 1975 level elsewhere. This provides the results with a margin of conservatism, as industrial production appears to develop in a less material-intensive direction.

Our results are not forecasts of what will happen. The analysis is designed to serve as a basis for evaluating future options. Although the use of an input-output model simplifies reality, it provides sufficient consistency to support our conclusions.

In our approach we do not use econometric models that depend on various elasticities. Because of the large difference in energy prices between the time when empirical estimates of such elasticities were made and today, such models are of doubtful value for an analysis of future energy demand. Also, it is often hard to estimate the importance of a change in assumptions in such models (*12*). In our opinion, it is better to analyze long-term issues with a simple model and to explicitly discuss the uncertainties and their implications.

Table 1. Specific fuel and electricity demand numbers for the model pulp and paper manufacturing plants. The 1973 numbers are included for comparison (*4*). Values are gigajoules per tonne.

Product	1973 average		Model plants (1977 design)	
	Fuel	Electricity	Fuel	Electricity
Bleached sulfate*	20.4	2.8	13.1	2.3
Kraft liner†	18.7	3.6	11.7	2.8
Newsprint‡	10.5	7.4	4.0	7.2
Fine paper§	11.2	3.1	4.9	1.8
Soft paper‖	12.7	4.3	4.8	3.0
Cardboard paper¶	10.1	2.6	5.1	2.2

*Pulp dried for sale. †Sulfate pulp integrated with a Kraft liner mill. ‡Newsprint mill with mechanical pulp production. §Fine paper mill without pulp production. ‖Soft paper mill without pulp production. ¶Cardboard mill based primarily on waste paper.

Energy-Efficient Technology

In this section we discuss the sets of energy demand coefficients. The time frame for implementing the different technologies is discussed later, but in cases involving changes in the mix of industrial output or in the building sector, a 20- to 30-year period is implied.

Pulp and paper. The theoretical energy requirement for paper production is less than 0.11 gigajoules per tonne of dry wood (*13*). For the pulp and paper industry, which now accounts for 40 percent of energy use in Swedish industry, our analysis is based on a set of model plants designed in 1977. The designs represent what should have been ordered for new plants at that time (Table 1). One important improvement (compared to the average technology in 1973) was the use of a six-stage instead of a five-stage evaporation plant for waste liquor. The other improvements are based on good engineering practice (*14*). Because these plants were designed in 1977 and because of the 1979–1980 energy price increases, we made some modifications that reduce the energy demand numbers by an additional 10 percent.

We assumed that the production trend toward more paper and less pulp will continue along with the increase in the fraction of mechanical pulp, an electricity-intensive method of grinding wood into pulp. In spite of this, we find that the paper and pulp sector, compared to 1975, would reduce its specific use of energy by 54 and 62 percent, respectively, if best technology or advanced technology were introduced.

Steel. The theoretical energy requirement to make steel from iron ore is about 6.3 GJ per tonne of steel (*13*). Plants in Sweden now use three to four times as much energy. The iron and steel industry accounts for 15 percent of energy use in Swedish industry. We have identified four future structures of steel technology (Table 2). The specific energy demand with modern technology corresponds to the rationalization of the Swedish steel industry scheduled for the next several years. We use the average of this level energy and a maximum heat recovery level (structures 1 and 2) as best technology. Considering its different use of scrap, the Japanese steel industry is today slightly more energy-efficient than the average we assume. Several new pig iron processes are being developed in Sweden: Elred, Plasmasmelt, and Inred (*15*). We use the average of Elred and Plasmasmelt (structures 3 and 4) as advanced technology. Energy use in the Swedish steel industry would in 1976 have been lowered by about one-third and one-half, respectively, if best and advanced technology were used.

We estimated the energy efficiency of other industrial and commercial sectors under various technologies, including heat recovery, improved insulation, heat pumps, new lighting technology, and electric drive control. The results, which show improved end-use efficiency, are expressed as specific energy demand numbers (Table 3).

Buildings. The potential for more efficient use of energy in buildings is very large. The government has a 10-year plan aimed at reducing energy use in existing buildings by about one-third. This level of efficiency is optimized for an energy price about 30 percent below 1981 prices (*16*). The increase in efficiency will be achieved through improvements in insulation, windows, and heat recovery. The plan is used as the basis for best technology in existing buildings.

Several newly built, energy-efficient homes and office buildings feature improved insulation, heat recovery, triple-glazed windows, and heat pumps. The Folksam building in Stockholm, com-

Table 2. Specific energy demand numbers for steel production. Half the production is assumed to be based on scrap (as was the case during the past decade). Values are gigajoules per tonne.

Source of energy	1976	Energy structure: 1 Modern technology*	2 Maximum energy recovery†	3 Elred‡	4 Plasmasmelt§
Electricity	2.9	1.8	1.8	1.3	4.2
Oil	7.6	4.3	2.2	1.3	1.3
Coal	11.9	9.0	9.0	9.4	3.3
Total	22.3	15.1	13.0	11.9	8.7

*This energy structure should result from changes planned for the mid-1980's by the Swedish steel industry. †Same as modern technology, but the potential for energy recovery with commercial technology now available has been fully exploited. ‡Same as modern technology, but the blast furnaces are substituted by a process called Elred, which is under development by Stora Kopparberg AB (*15*). §Same as modern technology, but the blast furnaces are substituted by a process called Plasmasmelt, which is under development by SKF Steel AB (*15*). A third process, Inred, is being developed by Boliden AB, but comparable data were not available at the time of this analysis (*15*).

Table 3. Specific energy demand numbers for industry. Each number is referenced to the 1975 number, 100. Numbers for 1990 were forecast by the National Swedish Industrial Board.

Industry	Fuel: Forecast for 1990	Fuel: Best technology	Fuel: Advanced technology	Electricity: Forecast for 1990	Electricity: Best technology	Electricity: Advanced technology
Agriculture, hunting, fishing	80	70	60	105	100	70
Forestry and logging	80	70	60	105	100	70
Mining and quarrying	110	64	35	145	96	96
Protected food	83	65	50	145	100	70
Import-competing food	83	65	50	145	100	70
Beverages and tobacco	83	65	50	145	100	70
Textiles, apparel, leather	77	65	50	164	100	70
Wood and wood products, including furniture	81	65	50	104	80	50
Printing, publishing, and allied industries	96	80	60	133	100	70
Rubber products	89	65	50	116	100	70
Chemicals, fertilizers, and plastics	75	60	55	79	65	60
Petroleum refining and petroleum and coal products	75	70	60	80	75	70
Nonmetallic mineral products, except products of petroleum and coal	81	70	60	140	100	90
Basic metals industries	86	51	32	102	49	73
Fabricated metal products and machinery except those used in shipbuilding and repairing	86	43	35	104	85	75
Shipbuilding and repairing	92	80	60	116	100	70
Other manufacturing industries, public semi-industrial activities	81	70	60	146	100	70
Electric light and power, steam and hot water, gas and water works	100	80	60	100	90	70
Construction	60	55	50	95	85	70
Wholesale and retail	60	25	20	95	35	25
Transport, storage, and communication	90	90	80	95	90	60
Letting of dwellings and business services	60	25	20	95	35	25
Private services	60	25	20	95	35	25
Paper and paper products	81	40	33	104	70	58
Others	100	100	100	100	100	100

pleted in 1977, is an example of best technology for office buildings. The thermodeck principle (*17*) is used to equalize day and night temperatures. A total of 150 megajoules per square meter per year is supplied for heating, compared with an average of 900 MJ/m^2 for comparable office buildings in Sweden.

One of the best energy-efficient single-family dwellings is a home outside the city of Uppsala. Uppsala has 3800 heating degree-days (Celsius) per year, or about 9 percent more than in Stockholm. This super-insulated house has a floor area of 130 m^2, a mechanical ventilation system with heat recovery, and a number of thoughtful design details. The capital investment was slightly below the norm for a home of comparable size because a central oil heating system was avoided in favor of a few small resistance heaters and a wood stove. The energy input from electricity (60 percent) and wood (40 percent) for heating and hot water is about 110 MJ/m^2 per year (*3*), compared with an average of about 800 MJ/m^2 for single-family dwellings in Sweden.

Swedish building codes in 1981 required new building designs to be optimized for an energy price of about 0.4 cents per megajoule (1980 prices), or one-third of the consumer oil price. Building codes of today are therefore not stimulating an optimum level of energy efficiency.

Automobiles. Average automobile fuel economy in Sweden is now 1.05 liters per 10 kilometers. The 1981 models averaged 0.90 liter per 10 kilometers. There are now automobiles on the market with a fuel economy of about 0.5 liter per 10 kilometers. This number was therefore selected as representing best technology. The improved fuel efficiencies are being obtained through such modifications as improved engines, lighter materials, reduced friction in transmission and tires, and reduced air drag. Prototypes are now reachng 0.3 liter per 10 kilometers, and this value was adopted as representing advanced technology (*18*).

Table 4. Breakdown of annual energy use by economic sector for a case with a 50 percent increase in the consumption of goods and services and average end-use technology comparable to that of best technology. Energy demand in 1975 is included for comparison. Values are petajoules per year.

Sector	1975 Total use	1975 Electricity	Base case Total use	Base case Electricity*
Industry	547	138	450	150
Transportation	230	7	190	10
Buildings†	446	76	150	90
Others‡	130	39	80	40
Bunkering for shipping	47	0	30	0
Total	1400	260	900	290

*Excluding electric heating. †Commercial and residential. ‡Agriculture, forestry, and construction.

Total Energy Demand

Because future economic growth is uncertain, our calculations of total energy use were performed for various combinations of end-use technologies and different levels and mixes of goods and services. As a base case we have chosen a 50 percent increase, relative to 1975, in the consumption of goods and services. This value is based on today's consumption mix, but due to the effects of saturation, we assumed an increase of 35 percent in the floor area of dwellings and an increase of 25 percent in distance traveled in personal transportation instead of 50 percent. As illustrated in Fig. 3, these changes increase energy demand by 39 percent instead of 50 percent at 1975 levels of consumption of goods and services and energy intensity. Available technology will have a strong impact on energy demand if implemented. With best technology and advanced technology, energy demand would be reduced 35 and 50 percent, respectively, even with a 50 percent increase in the consumption of goods and services. Sensitivity calculations for the base case with best technology illustrate the importance of variations in other parameters.

Sweden has traditionally been a large exporter of such materials as steel, iron ore, paper, and pulp. Maintaining the same mix of exports as in 1975 would increase annual energy use about 10 percent. Shifting exports to engineering products would reduce annual energy demand about 8 percent.

Internationalization (total imports divided by total domestic demand) in the base case was assumed to be 47 percent (*19*). Internationalization at the 1975 level, 29 percent, and at a higher level, 65 percent, would change annual energy demand by -3 and $+3$ percent, respectively, relative to the base case. This indicates that the energy intensity of exports and imports is roughly equal (excluding energy items).

A doubling of public expenditures would allow for a 26 percent increase in private spending to keep economic growth at the 50 percent level. This would result in a 6 percent lower annual energy demand. To illustrate the importance of the mix of household expenditures, total household consumption was broken into 13 categories. In two calculations, the six most and the six least energy-intensive categories were accorded the total increase in household spending. This resulted in an 8 percent effect, higher or lower, respectively, on annual energy demand.

Our calculations thus indicate that two

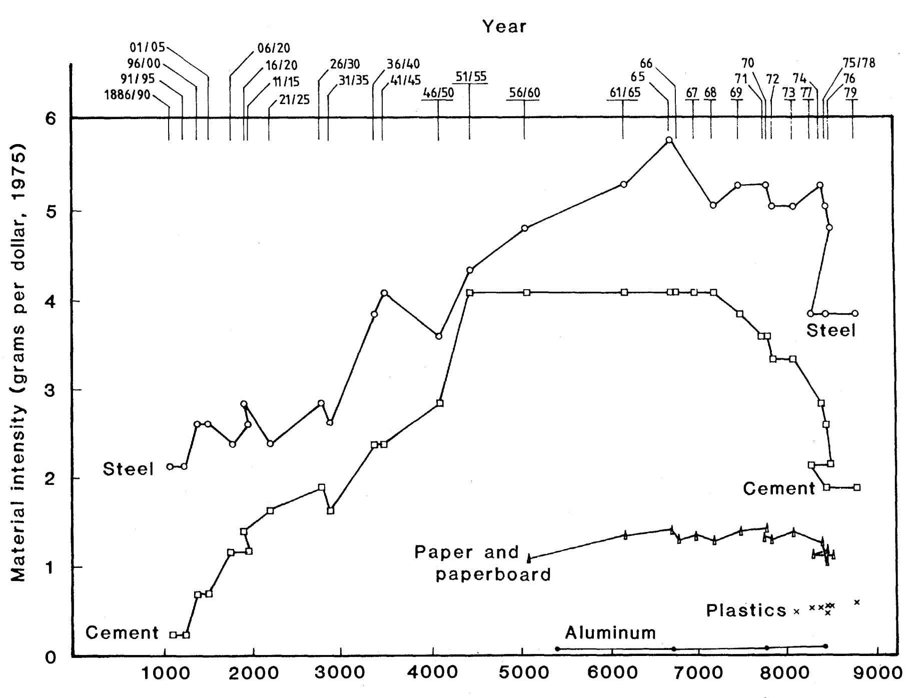

Fig. 2. Material intensity in the Swedish economy versus standard of living. Supply is production + imports − exports ± change in stock.

important parameters are overall level of consumption and choice of technology. For different levels of consumption and energy efficiency the final energy demand can be derived (Fig. 4). The level of consumption, both public and private, is expressed as a percentage of the 1975 level. Figure 4 shows that the 1975 level of total energy end use, 1400 petajoules, would be reduced as more efficient technology is introduced. With best technology and a 50 percent increase in the consumption of goods and services, final energy use would decrease 35 percent to 900 PJ per year and 50 percent if advanced technology were used. The breakdown by sector for the base case is shown in Table 4.

The electricity fraction of total energy demand would increase considerably. We refer to electricity for electric-specific purposes only, such as lighting, electrolysis, and motor drive but not for space heating. In the base case the demand for electricity would be 80 terawatt-hours, as compared to 66 terawatt-hours in 1975.

So far we have not addressed when these improvements in energy efficiency might be realized. The answer depends on the volume of investments and the choice of technology (Fig. 4). A 50 percent increase in consumption of goods and services between 1975 and 2000 (*19*) implies an annual growth of about 2 percent in the economy. Through different combinations of production factors, investments, and technologies, different development scenarios can be generated (Fig. 4).

New technology (that is, best technology) may be introduced at the rate of capital turnover in society. Industrial machinery and equipment have an economic lifetime of 10 to 20 years, depending on the sector of industry in which they are used. The automobile fleet is renewed about every 15 years. The structural components of buildings have a long lifetime (50 to 100 years), but many energy-related installations have shorter lifetimes. For example, furnaces, windows, ventilation systems, and facades last 10 to 30 years.

Using these rates of capital turnover, we calculated the impact of best technology and advanced technology on average specific energy demand. Best technology was assumed to be installed in all installations beginning in 1985 and advanced technology in 1995. We assumed no further improvements in end-use technology after 1995. This is a conservative assumption, as the limits set by thermodynamics are still far away. We conclude that today's best technology might represent the average technology by 2000. Advanced technology might represent average technology during the first decade of the next century, if introduced at the present rate of capital turnover.

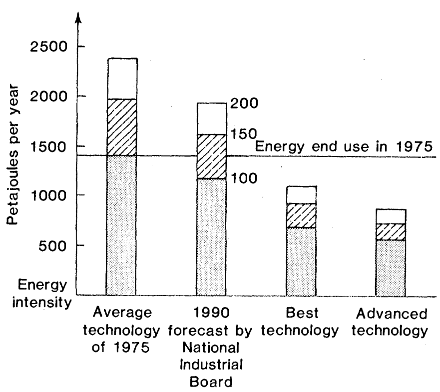

Fig. 3. Final energy demand for four levels of energy intensity at 100, 150, and 200 percent of the 1975 level of consumption of goods and services.

Uncertainties

The implications of uncertainties about the future development of the economy and about what technology will actually be used are evident in Fig. 4. Changes in life-styles are not assumed in the analysis. We deal here with uncertainties associated with simplifications in the model and with some of the input data.

The use of new technology in industry and shifts in production toward less material-intensive goods would change the input-output coefficients. We have not, however, changed these coefficients in the calculations. Only partial consideration was given to changes in individual sectors of industry. For example, the shift from pulp production toward more paper production was accommodated by changing the specific energy demand number. The use of constant input-output coefficients tends to overestimate the future energy demand number if the economy is moving toward less material-intensive production.

Consumption is affected by the relative prices of different goods and services. We have implicitly assumed a constant relation between the future costs of different production factors. In 1975, the initial year of our analysis, the economy had not adjusted fully to the oil price increases of 1973 and 1974. Therefore, the demand for energy-intensive products reflected in our input data is probably too high. To some extent we have accounted for this by assuming that the increase in transportation and construction will not be proportionate to the increase in total consumption.

These considerations suggest that the calculated energy demand associated with each combination of consumption level and end-use technology is high rather than low.

Will the New Technology Be Used?

Swedish energy policy has not been aimed at reduced fuel consumption per se. Rather, the primary objective has been to blunt the effects of oil price increases on industry. Energy conservation efforts in the housing sector appear mainly designed to offset increases in costs due to energy taxes. Rates in the electricity sector are below long-term marginal production costs. Furthermore, there has been no systematic effort to adjust energy prices to reflect external effects of energy use, such as high oil dependence and environmental effects, suggesting that energy prices are lower today than the national cost of energy use.

Some of the new technologies will be adopted as a consequence of energy price increases. Whether a given technology is considered economic may depend on whether one's point of view is corporate or private. Differences in fi-

Fig. 4. Relation between economic consumption, energy intensity, and total final energy use (in petajoules per year).

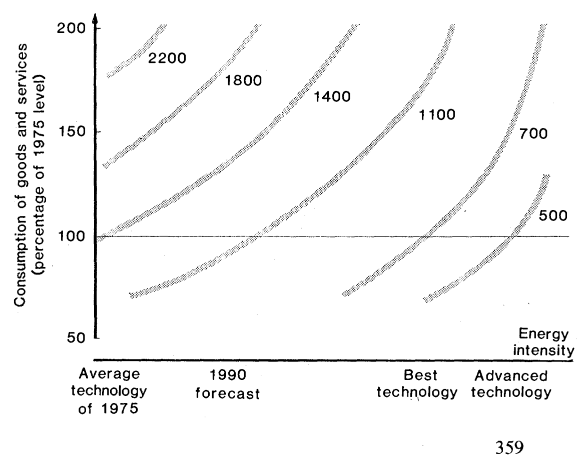

Table 5. Energy system for Sweden around 2005 for a case with a 50 percent increase in the consumption of goods and services and average end-use technology comparable to that of best technology. The 1980 numbers and the official 1990 forecast are included for comparison (*23*). Values are petajoules per year.

Source of energy	1980	1990	2005
Primary hydropower	250	280	280
Wind		0 to 4	40
Black liquors and wood in industry*	129	150	140
Wood energy†	6	90 to 110	120
Peat		22 to 40	50
Solar heat‡		4 to 11	5
Waste energy§		11 to 14	5
Nuclear fuel	275	610	
Oil	1070	500 to 690	
Natural gas		14 to 32	
Coal and coke	67	160 to 220	360
Alcohols		4 to 11	
Biomass farms			
Gross energy supply	1800	2000 to 2100	1000
Conversion and distribution losses	430	600	100
Final energy end use	1370	1400 to 1500	900

*Waste material in the pulp industry. †Fuel wood, wood chips, and forestry and agricultural residues. ‡Low-temperature heat. §Energy from industrial processes.

nancial condition or organizational design may also be influential. In some cases the use of energy-efficient technology may depend on government action.

Best technology is likely to be used in the renewal of industrial processes because it is available and economic. An industrial policy that enhanced renewal investments would thus also be an energy conservation policy. This refers to new processes only. The opportunities for retrofitting have been neglected in this analysis. Therefore, no extra capital costs would be involved in realizing these energy demand levels.

Energy-efficient technology is less likely to be quickly adopted by the building sector, since current building codes do not stipulate an economic level of energy efficiency. For buildings and automobiles (*20*) the total cost is fairly indifferent to the level of fuel economy, suggesting that noneconomic arguments may determine the choice of technology. Regulations and incentives to promote the use of energy-efficient technology may thus be important.

Implications for the Supply of Energy

The above analysis shows that reductions in energy demand could be an important energy policy option. Expansion of the energy supply system may make it difficult to achieve large reductions in energy demand. With large investments in energy supply facilities already made, marginal costs will be low for some time, as will the incentives for more efficient use of energy.

The interaction between a continued expansion of the energy supply and measures to improve end-use efficiency is of great interest to planners. From the standpoint of national economics, investment policy based on replacement costs seems justified because end-use technologies have lifetimes of one to two decades. Traditionally, investment decisions have been based on preconceived notions about specific technologies. It is more desirable to base such decisions on life-cycle costs of alternatives in which direct and indirect costs are accounted for.

In 1981 Parliament directed that Sweden's dependence on oil be reduced and that nuclear power be phased out by 2010. Energy is to be supplied by sustainable energy sources, preferably domestic and renewable. Parliament also asked that energy be used more efficiently.

In accordance with these goals, we have outlined a system to supply Sweden with energy at just after the turn of the century (Table 5). The hydropower contribution and the contribution by black liquors (waste products from the pulp mills) remain at about today's levels through the period. Contributions from peat and forest products are slightly above the government's plan for 1990. The wind power contribution is considerably larger than that envisioned for 1990, but well below the estimated potential. Oil, coal, gas, and biomass plantations are assumed to contribute about 360 PJ per year at the turn of the century, including 36 PJ per year from coal used for iron ore reduction in the steel industry. The supply of electricity would be based on hydropower, with important contributions from wind power and cogeneration.

It was previously shown that a fully renewable solar energy system might be built in Sweden (*2, 21*). However, the system was designed for an energy demand of almost 2200 PJ per year. It obviously is much easier to design a fully renewable system for an energy demand of about 900 PJ per year. Energy farms are now the subject of a major research program in Sweden. Fast-growing poplars and willows have an estimated potential of 360 to 540 PJ per year. This assumes the use of 1 million hectares of land, or 4 percent of Sweden's forest area (*22*).

Oil imports could be reduced considerably and domestic energy sources would rapidly become dominant if total energy demand were reduced from its present level.

Conclusions

New technology being introduced in industry, transportation, and buildings is much more energy-efficient than the average technology now in place. Thus the renewal process is an important mechanism for generating increased energy efficiency. New technology has in general not been more capital-intensive than the old. If this holds for the future, no extra capital will be needed to increase energy efficiency. In addition, opportunities exist to reduce energy demand even further. To what extent such opportunities should be exploited depends on noneconomic parameters, such as environmental effects.

Energy conservation has often been associated with sacrifice and deprivation. It has focused on conservation within existing energy-using installations, and its potential has been regarded as limited. If instead the change in future energy demand is regarded as the result of the continuous renewal process in society, very different results emerge.

There is ample opportunity to respond to higher energy prices by technological means. Combined with structural changes in both the production and demand sides of the economy, this presents an entirely new perspective. For example, energy demand in Sweden could economically be reduced to half the present level even under conditions of continued economic growth. These results may have far-reaching implications for future investment levels in energy supply systems and for the orientation of energy policy. Since Sweden uses about half the energy per dollar of gross domestic production as the United States, we believe that the potential for increased energy efficiency may be as great for other industrialized nations as for Sweden.

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Obsidian Dating and East African Archeology

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Summary. New experimental procedures have made it possible to establish specific hydration rates for the numerous compositional types of obsidian to be found at archeological sites in Kenya. Two rates are applied to artifacts from the Prospect Farm site, revealing a history of occupation extending back 120,000 years.

East Africa has been regarded for some time as an ideal archeological region for obsidian hydration dating (*1*). Obsidian artifacts are common in prehistoric sites of the area, and the dating technique can potentially provide ages for artifacts 1/2 million years old, beginning with sites as recent as 150 years. Although the technique has been known for 20 years (*2*) virtually no attempt was made until recently to apply hydration dating to this region. In contrast more than 10,000 obsidian dates now contribute to regional chronologies for western North America and Central America.

At the Pennsylvania State University Obsidian Dating Laboratory, a broad program of basic research on obsidian hydration was under way, and it seemed appropriate to illustrate recent developments in the dating technique by a practical application to East Africa. Obsidian artifacts representing site collections from throughout Kenya, but principally the Naivasha-Nakuru basin region (Fig. 1), were made available for study.

The Obsidian Dating Technique

The dating of obsidian artifacts is based on the fact that when a fresh surface of obsidian is exposed to the atmosphere, the diffusion of ambient water causes a hydrated layer to form just below the surface. The thickness of this hydrated layer, which varies from less than 1 micrometer to more than 50, depending on the time of exposure, can be measured by optical microscopy.

Because the hydration of obsidian is a diffusion process, it should obey the equation of Friedman and Smith (*2*)

$$x^2 = kt \qquad (1)$$

where x is the thickness of the hydrated layer, k the hydration rate, and t the time. The hydration rate is temperature dependent and follows the Arrhenius equation

$$k = Ae^{-E/RT} \qquad (2)$$

where A is a constant, E the activation energy, R the universal gas constant, and T the temperature. Combining Eqs. 1 and 2 gives

$$x^2 = Ate^{-E/RT} \qquad (3)$$

Accelerated Hydration Experiments

Various accelerated hydration experiments have been undertaken in connection with the depth-profiling of hydrogen by ion-beam techniques (*3*). Of greater practical importance to archeologists, however, are experiments that produce sufficient hydration so that observation and measurement by optical microscopy are possible.

In 1966 Friedman *et al.* published the results of an experimental hydration of obsidian from the Valles Mountains of New Mexico at an elevated temperature of 100°C (*4*). Freshly exposed obsidian surfaces underwent induced hydration at varying lengths of time up to 4 years. The results supported Eq. 1. After a

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