LBL-4430 c.2
ERG-76-09

EFFICIENT ENERGY USE AND WELL-BEING

The Swedish Example

Lee Schipper
A.J. Lichtenberg

April 1976

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

To be submitted for
publication

LBL-4430
ERG-76-09

EFFICIENT ENERGY USE AND WELL BEING THE SWEDISH EXAMPLE[*]

L. Schipper[§]

A.J. Lichtenberg[¶]

Work done under
U.S. Energy Research and Development Administration
Contract W-7405-ENG-48

---

[*] This work was supported in part by the Energy and Environment Division of the Lawrence Berkeley Laboratory with Funds provided by the Energy Research and Development Administration. Opinions are solely those of the authors.

[§] Energy and Resources Group and Lawrence Berkeley Laboratory, University of California, Berkeley, California. Also supported by a stipend from the Society for the Advancement of Scandinavian Studies.

[¶] Chairman, Energy and Resources Group, University of California, Berkeley, California.

Please address correspondance to the authors at

Room 100, Building T-4
University of California
Berkeley, CA 94720

ACKNOWLEDGMENTS

This is the first in a series of international energy use and policy comparisons. One of us (L.S.) thanks the Society for the Advancement of Scandinavian Studies for generous support during 1975. We also would like to thank many individuals who made their time and data available to us, including Drs. Bo Carlsson, Bertil Eneroth, Mats Höjeberg, Lars Kristofferson (in Sweden), Måns Lönnroth (Secretariat for Future Studies), and Hans Grönwall (Swedish Embassy) who coordinated our data collection and arranged many contacts for us, and Drs. Andreas Doernberg, Joel Darmstadter, Jeff Milstein, Steve Carhart, Clark Bullard, David Pilati, Bruce Hannon, Robert Herendeen, Arthur Rosenfeld, Eric Hirst, John Moyers, Steven Dole, Richard Norgaard, and James Just (in the U.S.), who provided assistance, data, or comments during the last year. Above all, our thanks to Drs. Jack Hollander, Mel Simmons, and Bob Budnitz of the Energy and Environment Division of LBL and Dr. John Holdren of the Energy and Resources Group, University of California, for their encouragement. Mr. Bob Stevens of LBL provided the graphics, while Mr. Bob Barton assisted with the editing and provided the railway photos. Tack så mycket!

COVER PHOTOS

FRONT

(Upper Left) -- *One of several oil-fired plants producing both electricity and district heat in Malmö (see Fig. 6).*

(Lower Right) -- *A Stockholm district local train terminating at Märsta being passed by a longer-distance northbound train. Passengers can ride the district train to here on their unlimited-ride monthly passes, then only have to buy an additional ticket for the rest of their journeys' distance.*

BACK -- *A steam powered local from Söderhamn, having joined the electrified main line, is here at Lenninge enroute to Bollnäs in the winter of 1948. Diesel locomotives have since replaced steam on unelectrified lines.*

EFFICIENT ENERGY USE AND WELL-BEING:
THE SWEDISH EXAMPLE

Lee Schipper and A. J. Lichtenberg

Energy and Environment Division
Lawrence Berkeley Laboratory
and
Energy and Resources Group
University of California
Berkeley, California 94720

ABSTRACT

A detailed comparison is made between the per capita energy consumption in the U.S. and Sweden. Sweden uses between 55% and 65% of the per capita energy (depending on the way hydro-electricity is counted) at essentially the same per capita income. It is shown that this difference arises both from differences in the mix of economic activities and from the differences in the energy consumption per unit output of these activities. The most important contributions to the differences in energy use arise from higher efficiencies in transportation, materials processing, and space heating in Sweden. Differences in the mode mix in transportation, particularly the reliance on the automobile in the U.S., also contribute significantly to the lower Swedish energy use. The more severe Swedish climate substantially increases the need for space heat relative to the U.S., obscuring dramatic differences in space heating efficiencies. Energy costs have played an important role in creating a more energy efficient economy in Sweden, aided by institutional and cultural factors. The comparison suggests that more efficient energy use will not interfere with and can in fact improve the functions of the United States economy over the long run.

CONTENTS

I. INTRODUCTION

Although it is often said that a direct relationship exists between per capita energy use and standard of living, as measured by Gross National Product (1,2), examination of the energy and GNP statistics for the most industrialized countries indicates a large spread in the ratio of energy use per unit of GNP (see Fig. 1). This article compares energy use in the United States, one of the countries with high energy use per unit of GNP, with that in Sweden, a country which in 1971 used approximately 60% as much energy as the U.S. to generate each dollar of GNP. Sweden was chosen not only because of its low energy to GNP ratio, but also because the GNP per capita is essentially the same in both countries. Moreover, much of the economic activity and many of the demographic features are similar to those in the United States. Thus evaluating the differences in energy utilization between these two countries may illuminate strategies for saving energy.

Studies of energy conservation in the United States indicate that the more important of these strategies, taken together, could reduce energy consumption 25 - 40% (3-5), while lowering pollution (4), reducing capital requirements for energy production (4), and generally raising employment (4). But the interrelationships among economic inputs including energy within an economy are complex. Thus examination of an economy that requires substantially less energy than our own may provide guidance in understanding the total effect of energy conservation.

Interest in energy use and conservation has stimulated a number of international comparisons (6,7) as well as new evaluations of data from within single countries (8,9). A preliminary study concerned with a number of countries shows some of the differences reported here without drawing conclusions (10). A study of the U.S. and West Germany developed comparisons further, discussing methodologies, and obtaining conclusions concerning possibilities for energy conservation in the U.S. in qualitative agreement with our Section V (11). Two other comparisons of U.S. and Swedish energy consumption differences have been undertaken (6,7), and we are grateful to have been able to compare our data with theirs. Although there are many small discrepancies in data from different sources, in no cases are these discrepancies large enough to change our general conclusions.

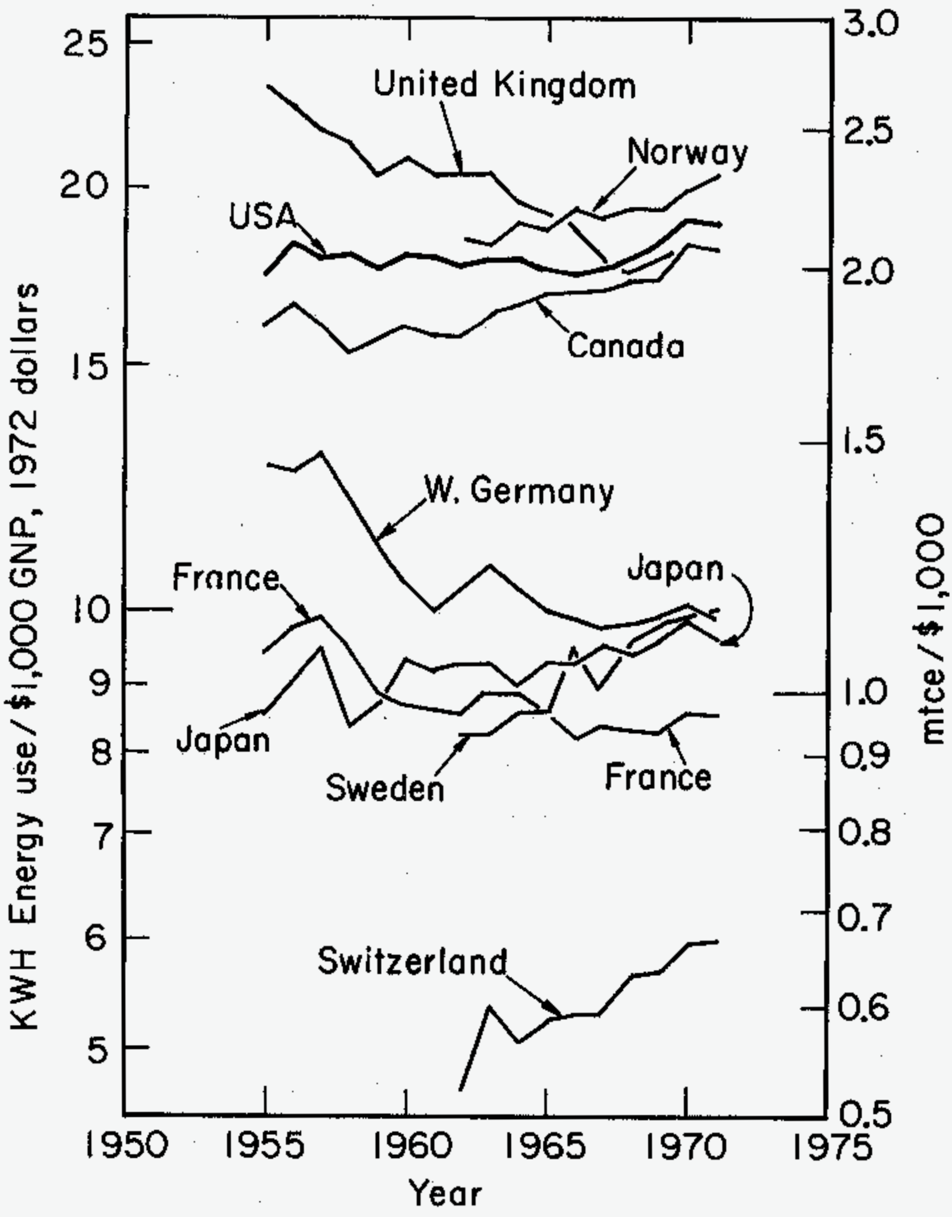
Except where popular use dictates American units (e.g., miles per gallon, deg-days Farenheit) we use kilowatt-hours as our standard unit; kWh means fuel or electricity used in end consumption; kWh_e refers to electricity only, while kWh_t refers to total consumption of energy with electric conversion losses included at the rate of approximately 2 kWh lost per kWh_e produced. All tons are metric.

II. GENERAL OBSERVATIONS REGARDING ENERGY USE AND INTERCOUNTRY COMPARISONS

Many factors enter into the determination of the ratio of energy use to GNP. Among these are energy costs relative to other costs, government policies including taxes, subsidies and regulations, and demographic and cultural variables. These factors combine to set a price for energy relative to other goods and services. Changes in energy use can, in principle, be determined from the elasticity coefficients for the demand for energy with respect to a set of independent variables.

Although a set of independent variables is difficult to define, it is generally agreed that the price elasticity of demand is a meaningful econometric quantity. The elasticity of demand e is usually defined as the percent change in demand that occurs when the price changes by one percent. One must distinguish, however, between short run and long run elasticities. Over a short period most responses to price are generally inelastic, i.e., the percentage change in energy consumption is smaller than the percentage change in price, while on a longer time scale many goods tend to be price-elastic. For example, if the cost of residential heating rises substantially, then in the short run householders will turn down their thermostats slightly and be more careful with ventilation, etc., to effect energy savings; but it is only over a long period of time that better insulation and other major energy saving designs, manifested primarily in new dwellings, will produce large energy savings. Econometrically determined long term elasticities are generally found to be substantial. A study of the long term elasticity of electricity in the U.S., for example, gave $e = 1.2$ for residential use, $e = 1.8$ for industrial use, and $e = 1.4$ for commercial use (12). Recent studies for gasoline indicate the long term elasticity may be as high as 0.75 (13).

The long run effects of energy prices can be seen qualitatively in Fig. 1. The "high" energy/GNP countries are those that historically have had cheap energy (relative to other goods and services); the U.S., Canada, Great Britain, and Norway (depending on how one counts the contribution of hydropower) are examples.



XBL7512-9188

Fig. 1. The energy/GNP ratio for several countries over time, with hydro power counted at 3 kWh_t/ 1 kWh_e. From Linden (1).

The countries with lower energy/GNP ratios are those that have been relatively fuel poor, especially since World War II. Although Sweden, for example, has had ample hydropower, the country has been increasingly dependent on imported petroleum. Consequently electricity has been inexpensive relative to fuel, with both price and per capita consumption very similar to that in the U.S. Motor fuels, on the other hand, have been taxed heavily in Sweden and consequently per capita consumption of these refined petroleum products has been far below the consumption in the U.S. Similar taxes have been the rule in other oil-poor countries. Although oil for home heating has been relatively inexpensive in Sweden (comparable to U.S. oil prices) the large amounts demanded for long winter heating seasons acted in place of higher prices to stimulate conservation efforts (14-18).

One factor often said to be of great importance in determining the energy/GNP relationship is the relative industrialization or type of industry in a country. Certain products are particularly energy-intensive, including steel, aluminum, cement, paper, and plastics. The effect of changing the output mix is most noticeable in comparing Luxembourg, where the steel industry plays a dominant role in the economic structure, with Switzerland, where banking, insurance, timepieces and other items of high value-added per kWh predominate. Luxembourg has an energy/GNP ratio of (51 $kWh_t/\$$) compared to Switzerland's (10.3 $kWh_t/\$$) (10). An earlier comparison of Great Britain and New Zealand noted a factor of two between the energy/GNP ratios of these countries (5), part of which may be attributable to the degree of wealth based on agriculture in New Zealand. However, this effect is usually small among industrialized nations, as can be seen if the percentages of the GNP's of the countries in Fig. 1 in the agricultural, industrial, and service sectors are compared. The agricultural sectors are between 3 - 5% of the total GNP for most of the countries considered; if any correlation exists, it is between energy use and the services sector, which will be explored further in the specific U.S. - Sweden comparison below.

The effects of cultural and lifestyle differences on energy consumption are very difficult to quantify, but these effects are clearly very important. Cultural patterns, although not wholly controlled by the marketplace, may be tempered over long periods of time by prices and fuel availability. Some of the current intensive energy use patterns in the United States and Canada can be traced to the availability of fuel wood during the 19th century (19). In

1850, for example, with a per capita energy consumption of 30.8×10^3 kWh_t, including wood, the U.S. used as much energy per capita as Switzerland does today.

In comparing ratios of energy use to GNP, several methodological problems arise. Comparing the size and content of the gross national product has received considerable attention (20). In our study we give indications of the structure of the economy in Sweden and in the United States, highlighting the differences and similarities. Accounting for differences in climate, geographic factors, population distribution, etc., is also important; we have made comments on this problem where applicable. The problem of counting the contributions of hydroelectric power and of combined electricity/heat generation are thought to be important in international comparisons, and are treated in the Appendix. We find that no matter how one counts hydropower the difference in energy use between Sweden and the U.S. is large, especially since the largest contrasts appear in transportation, space heating, and process heat applications. The use of non-commercial sources of energy, usually considered only when discussing less developed countries, are important to our work because the paper industry in Sweden, which accounts for fully 13% of the total consumption of energy there, actually generates 60% of its fuel internally from waste forest products. Together with other waste products, including urban wastes, these non-commercial fuels account for 9% of Sweden's total fuel use in 1971 (21). Finally, a troublesome statistical problem is inconsistency between different information sources; for example, the fuel used by agricultural and construction equipment could be counted in transportation, or industry, depending on how figures are kept. Similarly self-generated electricity, district heating, by-product fuels (such as coke gas), non-commercial fuels, consumption of energy by energy producers, and so forth must be carefully sorted out. In this paper we believe we have resolved these various problems to the point that the remaining errors are only a few percent.

Table 1. Basic economic and social indicators for the U.S. and Sweden (1971).[a]

	U.S.	Sweden
Physical Characteristics:		
Population (million)	207	8.1
People/sq mi	57	47
Climate-heating (deg-day/yr(68°F))	5,500	9,200
Economic Activity:		
GDP (current $/capita)	5,051	4,438
Energy consumption (kWh /capita)	96,000	52,450
Steel (kg/capita)	620	680
Cement (kg/capita)	342	430
Fertilizer (kg/capita)	105	67
Paper (kg/capita)	224	540
Food (per day):		
kcalories/capita	3,300	2,850
Protein (g/capita)	99	80
Cereals (g/capita)	176	168
Meat (g/capita)	310	142
Health, Education:		
Doctors/1000 persons	1.5	1.35
Dentists/1000 persons	0.49	0.72
Hospital beds/1000 births	7.8	15
Infant deaths/1000 births	19	11.1
Teachers/1000 students	34	60
Newspaper copies/1000 persons	301	534
Books published/1000 persons	0.39	0.94
Conveniences:		
Telephones/capita	0.59	0.56
Television sets/capita	0.45	0.32
Autos/capita	0.45	0.3
Passenger-miles/capita (1970)	7,900	5,050
Refrigerators (% saturation of households)	100	93

(Table 1, continued)

	U.S.	Sweden
Freezers (% saturation of households)	28	46
Clothes washers (% saturation of households)	76	41
Vacuum cleaners (% saturation of households)	88	89

---

[a] Sources: U.S. Data from USSA (24), Swedish data from SEB (22), SÅ (23), and fact sheets distributed by the Swedish Institute.

III. SWEDEN AND THE UNITED STATES: PHYSICAL AND ECONOMIC COMPARISONS

We take the years 1970 - 1972 as our comparison period, because complete data are available and because energy prices and use trends were relatively stable compared to the post embargo period. Where appropriate we used data from other years. 1971 was a mild recession year for Sweden; total energy use was slightly higher in 1970, from which our Swedish industry statistics were taken. Unless otherwise noted we use the old exchange rate of 5.18 Swedish Crowns (skr) per dollar. This rate was as low as 3.92 skr/$ in 1973 and has stabilized at 4.38 skr/$ in 1975 (22,23).

In Table 1 we compare physical characteristics, economic activity, and various measures of well-being in the U.S. and Sweden. Although the populations differ by a factor of 25, the population densities are similar, as is the distribution into fairly populated urban centers and sparsely populated rural regions. Movement to the suburbs, fostered by the automobile, started earlier and is more advanced in the U.S., although there are signs of such a trend in Sweden (25,26). The natural distances over which goods must move is larger in the U.S., although in Sweden much of the lumber, iron ore, and electric power flows from the sparsely populated far north to the more crowded south. The climate in Sweden is more severe than in the U.S., in the sense that the number of degree days (based on 68°F) is far larger, varying from 7700 in the extreme south to over 12,000 in Norrland (17). We have estimated that the average number of degree days, weighted by population distribution, is close to 9200 in Sweden, thus comparable to North Dakota, while the weighted U.S. average is approximately 5500 degree days (27).

Economic activity indicates that in 1971 the U.S. had a 10% higher GNP per capita than Sweden (22-24) at the then current exchange rates (see Table 1). The striking difference, however, is the fact that for each dollar of GNP Sweden required only 60% (1971) as much energy as the United States. Subtracting the energy content of non-fuel imports and exports (see following) reduces the 1971 Swedish figure to 55%. Despite the lower energy use we note that the total per capita production of basic industrial commodities is quite comparable in Sweden and the United States.

Basic well-being is difficult to compare quantitatively. As seen in Table 1, food intake is similar, with Americans characteristically eating considerably more meat (about twice the Swedish per capita consumption), which per gram of protein is more energy-intensive than most other foods. In health and education, Sweden leads the U.S. in almost all categories. When the comprehensive health and social security system in Sweden is examined this difference is even more striking.

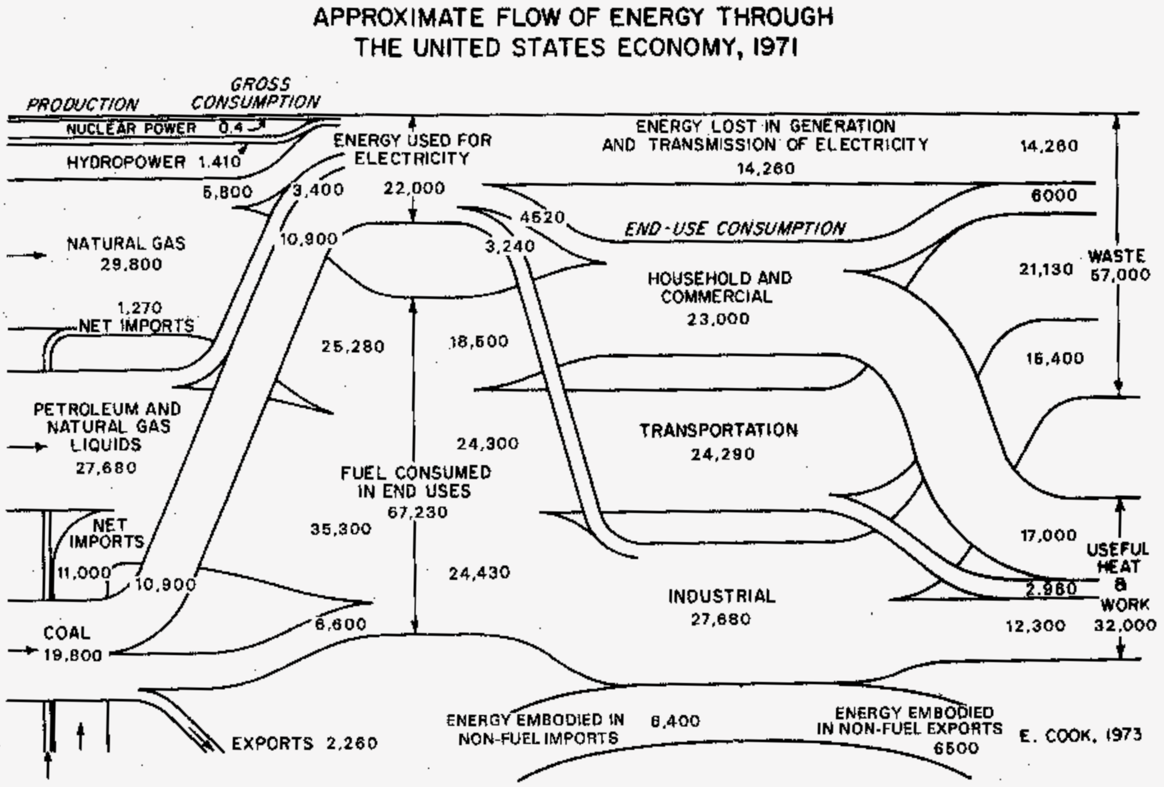
The large number of autos and TV's in the United States is accounted for mainly by multi-unit ownership by families. Transportation convenience is, in fact, quite comparable, because public transportation is more readily available in Sweden, while domestic distances are generally smaller. Sweden has also developed a very popular charter air travel system that provides low cost packaged tours to most of the popular tourist spots in southern Europe and Africa. Swedes have far more second homes (500,000 in all) per capita than Americans, and most of the population enjoys four weeks of paid vacation each year. Thus we conclude that the living standards are quite comparable quantitatively in Sweden and the U.S., but the mix is substantially different, emphasizing somewhat less energy-intensive economic activities and life styles in Sweden.

IV. COMPARISON OF ENERGY USE IN THE UNITED STATES AND SWEDEN

In Table 2 we compare energy use in the U.S. and Sweden. This table is further amplified in Figs. 2 and 3, in which the flows of fuel to each end use sector are shown. Sweden uses less energy per capita in all sectors, the largest difference being in the transportation sector. Considerable differences also exist in basic materials processing in the industrial sector, and in electricity use in the residential and commercial sector. We shall examine these differences in greater detail below.

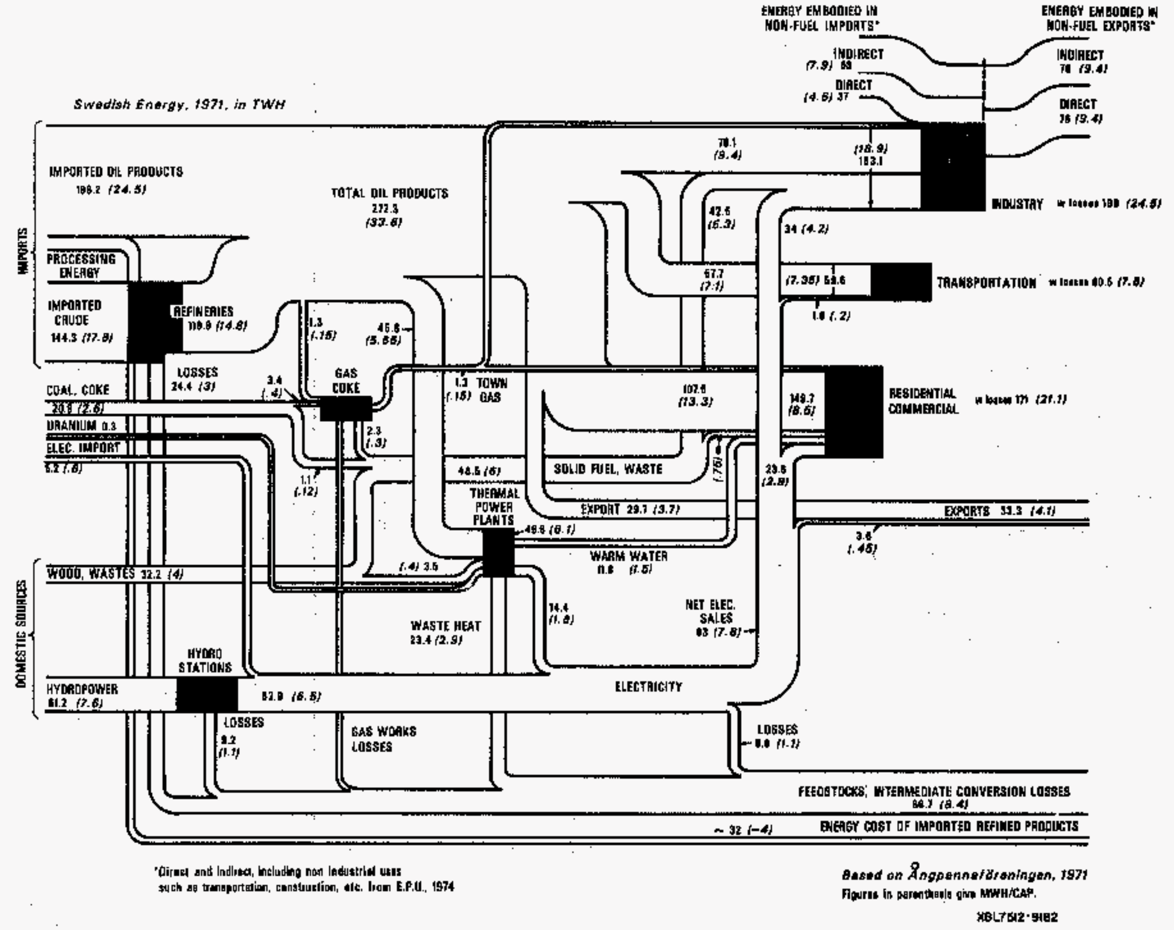
A useful formula that summarizes the uses of energy (T_J's) is: energy use = $\Sigma_J E_J D_J = \Sigma E_J' D_J' = \Sigma T_J$, where the D_J are the final dollar demands for goods and services, and the E_J are the energy intensities of those demands; or, in physical terms, the D_J' are the quantities of goods and services, and the E_J' the energy intensities associated with those quantities.

When data are disaggregated in this way, both the relative mix of modes (the D_J or D_J') and the efficiency of those modes $(E_J)^{-1}$ or $(E_J')^{-1}$ can be compared among countries. Energy use in the economy can be lowered both by shifting to less energy intensive D_J and/or by increasing the efficiency (lower E_J) of production of a given D_J. We shall use this formalism in the specific comparison of U.S. - Swedish energy use to follow. The above equation, however, can distort the comparison of energy efficiencies, because demographic differences affect



XBL761-5009

Fig. 2. Energy flow diagram for the U.S. All figures in kWh per capita. Import/export balance via non-energy goods estimated from Ref. (35) excludes process energy for refined imported fuels (ca 1800 kWh per capita in 1971). Excludes wood wastes (1000 kWh per capita) and feedstocks.



*Direct and Indirect, including non industrial uses such as transportation, construction, etc. from E.P.U., 1974

Based on Ångpanneföreningen, 1971
Figures in parenthesis give MWH/CAP.

XBL 7512-9182

Fig. 3. Energy flow diagram for Sweden, 1971. Figures are in TWh (= 10^9 kWh); figures in parentheses are MWh per capita figures, "With Losses" figures calculated by assuming 1.6 kWh_t/kWh_e. Import/export via trade from EPU (16) (excluding the energy cost of refined imported products, shown in the lower right hand corner). Other data from IVA (21). Figure based on one drawn by Ångpanneföreningen (31). Note the losses in hydropower.

Table 2. Energy consumption in kWh/capita for U.S. and Sweden in 1971.

	United States[a]			Sweden[b]		
	kWh	kWh$_e$	kWh$_t$[c]	kWh	kWh$_e$	kWh$_t$[c]
Transportation	24,025	25	24,075	7,350	200	7,775
Commercial	9,600	2,150	14,250	7,375	1,500	10,625
Residential	13,500	2,300	18,450	11,125	1,400	150
Industry	28,900	3,300	36,000	20,400	4,200	14,150
Feedstocks	5,600	--	5,600	2,500	--	2,500
Utility losses[d] (actual)	14,200	--	--	3,700	--	--
Actual consumption[e]	95,825	7,775	98,375	52,450	7,300	63,600
Energy embodied in foreign trade[f]	1,800[g]	--	1,800	-4,600[h]	--	-4,600
Net Consumption[i]	97,625	7,775	100,175	48,150	7,300	59,000

[a] U.S. data from Bureau of Mines (28), Cook (29) (see our Fig. 2 which excluded feedstocks), and Knecht and Bullard (30). We included 1,000 kWh per capita in wood wastes (SRI, ref. (30a)). Totals in kWh and kWh$_t$ columns do not agree because of difference in counting hydropower.

[b] Swedish data from EPU (16), IVA (21), and Ångpannef. (31), with feedstocks estimated from SOS (32) and EPK (33). Includes 4,000 kWh per capita wood wastes. Hydropower counted at 3,413 Btu/kWh$_e$ in kWh column.

[c] kWh$_t$ calculated by distributing utility losses to end consumers. "Self" consumption in electrical sectors counted in "Industry". kWh$_t$ column for U.S. includes hydropower at 10,460 Btu/kWh$_e$; kWh$_t$ column for Sweden counts all electricity at 10,400 Btu/kWh$_e$. Actual "heat rate" for thermal and back-pressure plants in Sweden has 8,870 Btu/kWh$_e$, including distribution losses, and 7,780 Btu/kWh$_e$ for production only. Co-generated electricity in paper industry excluded from this column.

[d] Hydropower counted at 3,413 Btu/kWh$_e$. Other losses according to actual consumption.

[e] Actual consumption refers to fuels and electricity including petroleum refining losses and other captive fuels.

[f] Embodied energy includes the process energy of refined fuels but *not* the energy available when the fuel is burned.

[g] Import-export energy balance for the U.S. from Herendeen and Bullard (35).

[h] Import-export energy balance for Sweden from EPU (16).

[i] Exports of coal, crude or refined products are excluded from this balance. They are shown in Figs. 2 and 3.

the amount of energy required to fulfill a given need (say, residential heating), thus affecting the D_J as well as the E_J. These factors are also considered in the U.S. - Sweden energy comparison. The differences in E_J's between countries indicate possibilities for energy conservation via technical change, without requiring changes in lifestyle.

A. Transportation

In Table 3 we display basic passenger transportation data for Sweden and the United States. It can be seen immediately that major differences exist in all modes. In addition to the striking differences in automobile D', E', and T, we note that Swedish passenger transportation is more heavily concentrated in rail (including subway) and bus modes, at the expense of the auto and the airplane. Significantly, all Swedish E_J''s are lower than the corresponding U.S. E_J''s. This is due in part to higher load factors and the extensive use of air and bus charters.

In Table 4 we consider the automobile in more detail. We see that the Swedish D' is only 62% of the U.S. figure, and E', measured in kWh/pass-mi or gallons/pass-mi is only 60% of the U.S. figure. The biggest contributor to efficiency is the lower weight of Swedish autos, compared to American counterparts. The average weight of a car used in Sweden is 1100 kg (2420 lb), whereas for the United States the average weight is 1700 kg (3740 lb). The weight distributions are given in Fig. 4 (43-45). Interpolating EPA measurements of fuel consumption versus inertial weight suggests that this difference alone reduces energy consumption per mile by ~ 30% (43). The lack of power extras, automatic transmissions, and air conditioners reduces fuel demand further, as does the lower ratio of engine displacement to car weight of Swedish autos.

Beyond these technical differences in automobiles, however, are more subtle differences in auto utilization that have significant consequences. For trips of 10 km or less, in which auto fuel consumption is nearly double the average (47), the Swedes use private cars and public transit in the ratio 55/45 (% of trips) (45). In the U.S., by contrast, the ratio is 90/10 (FHWA, unpublished data). This traffic accounts for 65% of all auto trips in the U.S., resulting in lower average driving cycle efficiencies. Thus it becomes apparent why actual miles-per-gallon in Sweden are higher than predicted by the EPA (43): the driving cycle demands less energy. Surprisingly, load factors in both countries average approximately two. Probably the reason the Swedish value

Table 3. Passenger transportation data for U.S. and Sweden.[a]

Passenger Mode[b]	United States (1972)			Sweden (1970)		
	D'_J (pass-mi/ capita)	E'_J (kWh/ pass mi)	T_J (kWh/ capita)	D'_J (pass-mi/ capita	E'_J (kWh/pass mi)	T_J (kWh/ capita)
Auto[c]						
< 30 mi	4,850	1.72	8,330	1,825	--	--
> 30 mi	4,200	1.02	4,300	3,225	--	--
Total	9,050	1.41	12,630	5,050	.74	3,760
(1970	7,900	1.41	11,200)			
Bus[d]						
Local < 30 mi	112	.50	56	460	.41	200
Intercity > 30 mi	122	.30	42	25		
Rail[e]						
Local < 30 mi	64	.21 (.63)[f]	13.7	85	.16(.48)[f]	15
Intercity > 30 mi	21.3	.87	18.6	356	.25(.75)[f]	90
Total Land	9,370	1.36	12,760	5,975	.68	4,065
Air Domestic	490	3	1,500	46	1.12(?)	275(?)
Air International[g]	243(?)	1.38(?)	335	200		
Other Passenger, Military	--	--	1,500	--	?	200
Total Passenger	10,103	--	16,095	6,221	--	4,540

[a] Sources: for U.S. data (36), (37), and (38); for Swedish data (40), (33), and (41).

[b] Division into urban (within areas of population 30,000) and intercity (from ref. (41)) do not exactly correspond to our classification by local (30 miles) and intercity.

[c] Ref. (36) gives 1969 load factors that imply an overall load factor for automobiles of 1.7, which seems unreasonably low. Refs. (37) and (38) imply load factors of 2.2, while ref. (42) assumes a load factor of 1.9, which we adopt. There was a similar discrepancy in the Swedish data, most references giving an implied overall load factor of 2, with one reference giving 1.7. We adopt 2, since the driving in Sweden is dominated by family driving to a greater degree than in the U.S. (The load factor is defined as the ratio of passenger miles to vehicle miles.)

[d] U.S. bus fleet is 75% diesel, Swedish bus fleet is 10% electric, the remainder either diesel or gasoline.

[e] Local rail service in the U.S. is electric, intercity is 75% diesel, the rest electric. In Sweden 90% of rail service is electric, the remainder diesel.

[f] Electricity figures are net, and the E_J in parentheses reflect a theoretical 3 kWh_t/kWh_e.

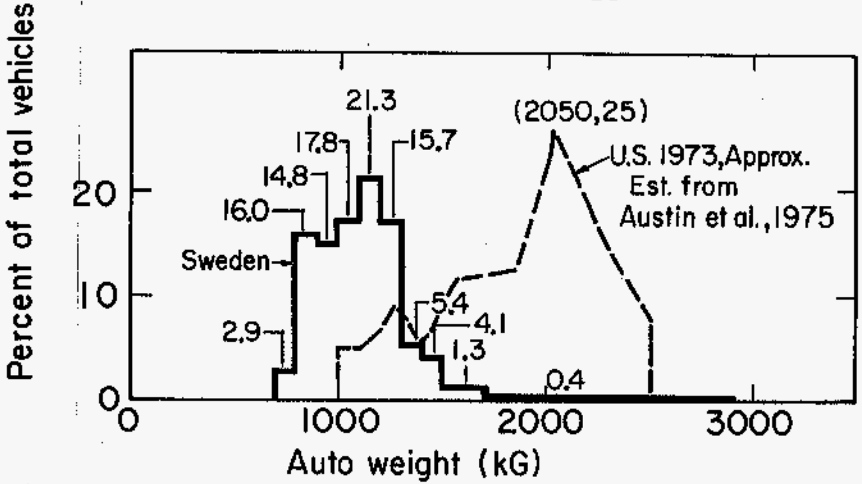
[g] The figures for international fuel and passenger miles are uncertain.

Table 4. Automobile data for the U.S. and Sweden (1970). (Conversions used: 1 U.S. gal = 33.75 kWh; 1 mi = 1.6 km.)

	U.S.	Refs.	Sweden	Refs.
Persons/vehicle	2.25	(42)	3.4	(16)
Licensed drivers/capita	0.8	(38)	0.4	(16)
Pass-mi/capita	7,900	(42)	5,050	(40)
Vehicle mi/capita[a]	4,160	(37)	2,560	(46)
Mi/vehicle	9,360	(37)	8,900	(37)
Load factor	1.9	(42)	2.0	(40)
Average weight (kg)	1,900	(43)	1,100	(44)
Miles per gallon[b]				
Actual	13.7	(37,43)	24	(43-45)
Theoretical	12.5		20	
kWh/pass-mi	1.4		0.73	
kWh /capita	11,200		3,710	

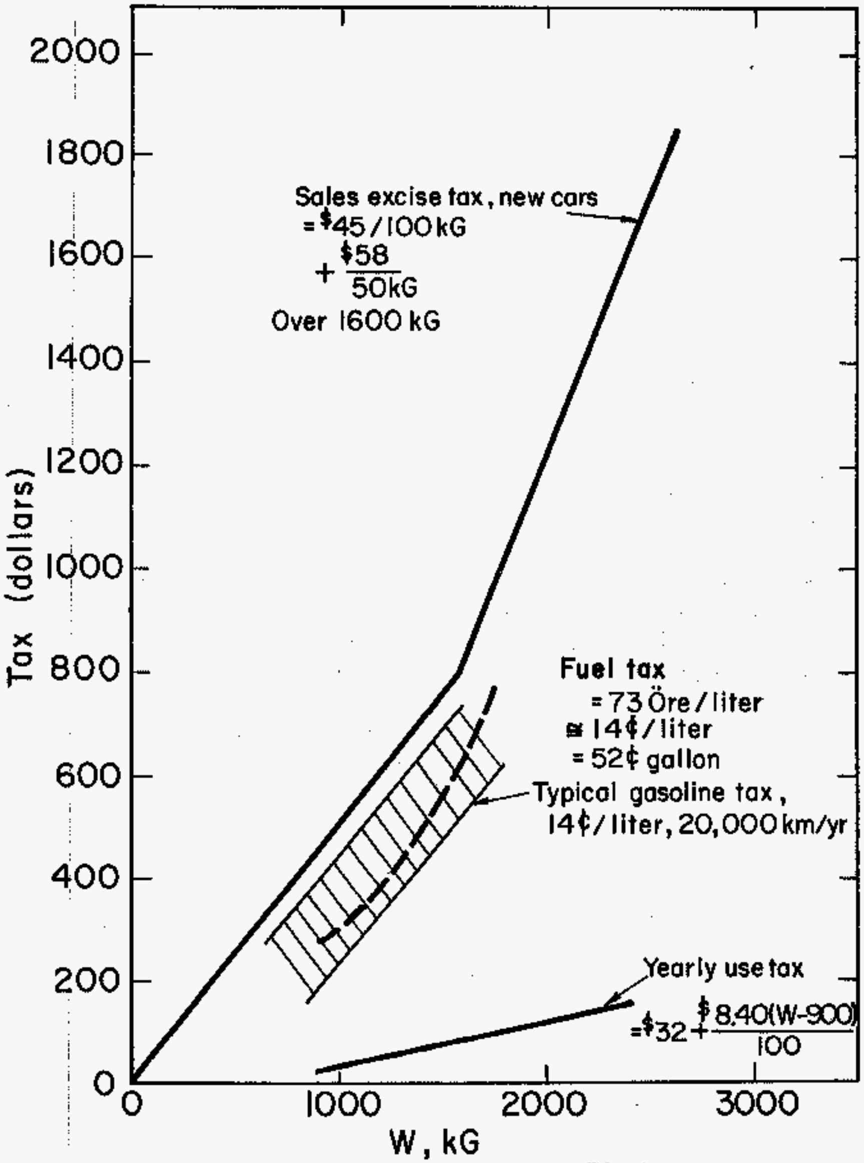
[a] The surprising similarity of miles driven per car suggests that in Sweden second cars are replaced by mass transit, and a significant number of families have no car at all.

[b] Theoretical miles-per-gallon is estimated from the weight-fuel economic statistics of the EPA. Actual is determined by dividing actual miles driven by fuel consumed. Swedish theoretical value (24 mpg) from Ullén (44) matches actual for Sweden.



XBL7511-9150A

Fig. 4. Distribution of autos by weight, 1974. From (44). Figures for U.S., 1973, estimated from (43).



XBL 7511-9150B

Fig. 5. Taxes on automobiles and gasoline in Sweden, 1974 (using the old exchange rate 5.18 skr/$). Shaded area and dotted line give estimate of gasoline tax as a function of weight. From (23), (44), (48).

is as low as in the U.S. is that the smaller families in Sweden compensate for that country's higher family use relative to commuter use.

A factor reducing Swedish automobile energy use further is that the speed limit was as high as 110 km/hr (68 mph) on only about 10% of the largest highways, with a 90 km/hr or lower (55 mph) limit on the remaining 90% of the main highways. This is in contrast to the U.S., where highway speed limits were commonly 65 mph (or greater) in 1971.

The availability and use of mass transportation in local and long distance travel is an important factor in the optimization of the use of the auto discussed above (25,26). In Stockholm, Gothenburg, and Malmö, representing more than 25% of Sweden's population, mass transit, motor bikes and pedal bikes account for 75% of all commuting (41). The figure for the entire country is 46%. Mass transit provides half of this, mostly in the above named cities. Most of the cities of over 50,000 people in Sweden have bus systems reinforced by important economic incentives, including subsidies, that encourage use by riders going into the city center. In Gothenburg, for example, one can obtain a round trip ticket for the price of a single fare by using the street cars and buses at off-peak daytime hours; in Stockholm and other cities a 50 skr (now 70 skr) pass allows unlimited transportation on all rail and bus lines. Buses are often as close as four minutes apart during peak hours, and rapid rail and buses provide direct service to locales as much as 40 km from the city centers. Thus to the city or suburban dweller in Sweden, mass transit presents a viable and economic alternative to the use of an automobile, and development of suburbs and new towns around rail and bus stations reflects the popularity of mass transportation. For longer trips, alternatives to auto transport in Sweden are also available. Inter-city buses, semi-charter buses, and trains carry 20% of the passenger miles in trips over 50 km. Swedish Railways offers hourly departures between Malmö, Gothenburg, and Stockholm during day and early evening hours, traveling at average speeds of 80 - 100 km/hr.

We should not omit, however, discussion of some of the discentives that discourage use of automobile transit in Sweden. In Stockholm no 24-hour free street parking exists in the greater downtown area and parking fines begin at $12.50. Both Stockholm and Gothenburg have set up systems of barriers, one way streets, mass transit-only lanes or passage ways, and pedestrian-only streets that further discourage the use of the auto. It has been noted (25,26) that some of the gains made against the auto have been gradually eroded. Nevertheless, the auto's share of all passenger miles has stabilized at 82% in Sweden (33); the U.S. figure is 92% (38).

The tax system has contributed strongly to the control of the auto in Sweden. In 1971, the gasoline tax of 50¢/gallon raised the price by 250% to 70¢/gallon (23,48). Automobile excise taxes and yearly fees rise in proportion to vehicle weight with the formula shown in Fig. 5. These fuel and weight taxes influence owners to purchase light cars, as the lack of cars above 1600 kg (the U.S. average) shows (Fig. 4). In addition, the excise taxes raise the cost of a new car relative to the cost of maintenance, making it more worthwhile in Sweden (*vis a vis* the U.S.) to keep an older car in running condition. The average car in Sweden has a lifetime of about 14 years compared to a U.S. lifetime of less than 10 years.

For freight transport, given in Table 5, the largest difference in per capita energy use is associated with distances through which goods are moved. A lesser, though still important, factor is the energy intensity of freight movement. Although a complete study of efficiency is yet to be made, some important factors can be identified. Among these we note that Swedish trucks are not prohibited from hauling freight on return trips. Also, small station wagons and four cylinder microbuses or diesel mini-trucks are used extensively for short hauls in Sweden, in contrast to the heavier pickup or panel trucks used in the U.S., thus more closely matching mode and vehicle to the demands of the task. Much of the difference in freight miles would be accounted for by shipments of Swedish exports of raw materials through other countries, exports that far outweigh (literally) imports. These are not counted in our study. Also, coal and other fuels are transported over much greater distances in the U.S. than are fuels in Sweden.

Energy used in foreign passenger travel, particularly in European countries where this constitutes a significant fraction of what corresponds to domestic travel in the U.S., may distort comparative energy use analysis. This is particularly true of air travel. Nearly every passenger flight connecting Sweden with anywhere stops in Copenhagen, where most of the fuel for the trip is put aboard. Thus Danish fuel intensity per air passenger mile is abnormally high (8), while that for Sweden is low (16). It is also difficult to credit passenger miles when foreign visitors travel to or within a country. Because of these uncertainties we have refrained from drawing conclusions from the great differences in E' (air passenger travel) seen in Table 3.

Table 5. Goods transportation data for the U.S. and Sweden.[a]

	United States (1972)			Sweden (1970)		
	D_J (ton-mi/ capita)	E_J (kWh/ ton-mi)	T_J (kWh/ capita)	D_J (ton-mi/ capita)	E_J (kWh/ ton-mi)	T_J (kWh/ capita)
Truck						
Local (0-30 mi)	360	1.95	700	339	0.58	200
Intercity (> 30 mi)	2069	0.63	1430	1284	0.86	1100
Total truck	2429	0.88	2130	1623	0.8	1300
Rail	4132	0.19	800	1350	0.6(.18)[b]	80
Domestic Air	20	7.5	150	--	--	--
Water						
Domestic	--	--	420	704	0.3	190
International	--	--	480	--	--	--
Total goods	6585	--	3980	3670	--	3170
Non-revenue goods transport (agric., forestry, construc., etc.)	--	--	1850	--	--	470
Pipeline	--	--	200[c]	--	--	--
Other	--	--	120[c]	--	--	930
Totals	6585	--	6230	--	--	4570

---

[a] Sources: U.S. data from Knecht and Bullard (30), FEA (39), and BNL (30b). Swedish data from (40), and EPU (16), with the breakdown for truck by distance based on the 1973 distribution.

[b] Figure in parentheses reflects 3 kWh_t/kWh_e conversion factor.

[c] 1971 data.

B. Residential and Commercial Energy Use

A comparison of energy use in the residential and commercial sectors is given in Table 6. Although the per capita consumption is significantly lower in most categories, a full appreciation of the differences are only obtained by examining the D_J''s and E_J''s separately.

Space heating, consuming over one half of the total (Table 7), shows very large differences in efficiency, when account is taken of the differing climates and the actual energy use per square foot of residential or commercial space. The larger number of degree days in Sweden is compensated for by considerably lower heating intensity (kWh/deg-day m^2). A study of insulation in Swedish homes and apartments showed that U-values for heat loss have declined steadily to a typical value of .06 Btu/hr ft^2-°F). One can almost guess the year of construction of a residence in Sweden by the U-values, the scatter from the average value for any year of building being very low (16). This indicates that additional factors have acted, via stringent building codes, to permit only energy efficient (and economic) construction in housing (52). In contrast, U.S. U-values have been set mainly by a weak FHA minimum property standard, which before 1971 was 0.12 Btu/hr-ft^2-°F for ceilings and 0.19 Btu/hr-ft^2-°F for walls (50). The U.S.-Swedish ratio of U-values of 2 is nearly equal to the average ratio of heating intensities. By implication, the Swedish houses also have correspondingly less infiltration and heat loss through glass, by use of storm windows and double glazing, to maintain the overall ratio (17).

Although the lower heat loss in Swedish houses is in part a response to the more severe climate, this is not the primary reason, as seen in Table 7 where we present the heating intensity in various regions in the U.S. and Sweden, so that intensity at a given number of degree-days can be compared. Although there is little overlap between the U.S. and Swedish degree-day values, the plots of intensity (kWh/m^2-deg-day) versus degree-days clearly lie on different curves for Sweden and the U.S. The Swedish values are also nearly independent of degree days, reflecting the centralized standards, probably indicating that before the embargo the standards were sufficiently high that there was little economic incentive, even in the extreme north, to exceed these standards.

In Sweden the mix of single family dwellings (SFD) 42% and apartments (MFD) 58%, is considerably different from that in the U.S. where in 1970 71% were SFD and 29% MFD. However, this difference does not account for much of

Table 6. Per capita residential and commercial energy use in the U.S. and Sweden (1972).

	U.S.[a]	Sweden[b]
Residential:		
Direct fuel (kWh)		
Heating	9,660	8,200
Water heating	1,950	3,300
Gas appliances	630	125
Second homes	--	300
Electricity (kWh$_e$)		
Refrigerator and stove	610	530
Lighting	335	105
Air conditioning	300	--
Other appliances	590	475
Heating	280	400[c]
Water heating	500	
District heating saving	--	1,300[d]
Total net use (kWh)	14,855	12,135
Electric conversion loss at U.S. rate[e]	5,230	3,020
Total gross use (kWh$_t$) (with actual losses)[e]	20,085 (--)	15,135 (12,820)
Commercial:		
Floor space (m^2)	10	13[f]
Direct fuel (kWh)		
Space heat	5,625	4,800
Water heat	790	--
Air Conditioning	200	--
Electricity (kWh$_e$)		
Air Conditioning	205	--
Lighting	1,250	625
Electric heat and other	310	1,075
Total net use (kWh)	8,380	6,500
Electric conversion loss[e]	3,530	3,200
Total gross use (kWh) (with actual losses)[e]	11,910 (--)	9,700 (7,280)

(Table 6 continued -- footnotes)

[a] Data from Refs. (3), (30b), (49), and (49a).

[b] Data taken from Refs. (16), (41), (53), and (54).

[c] Includes hot water in all-electric homes, and second homes.

[d] See Appendix for explanation and detailed calculation. Assigned to residential sector for convenience.

[e] Losses counted at U.S. rate of 2 kWh_t/kWh_e for purposes of uniform comparison, as in Table 2. Actual Swedish losses (0.46 kWh_t/kWh_e) reflected in total column in parentheses.

[f] This value is obtained from the volume of commercial office space (Ref. (16)) by assuming a 4-meter room height.

the increased heating efficiency, as the kWh/m^2 was only slightly lower in Swedish apartments than in single family dwellings, and the kWh/cap was also very similar, due to the higher number of people per house in SFD. In apartments common metering of all units in a building removed the incentive to conserve, raising both temperature and hot water use (41).

Electric heating in Sweden was increasing rapidly, as was U.S. growth, until the embargo of 1973 caused a re-evaluation of the overall effectiveness of such systems. In 1972, 7% of Swedish homes (15% of SFD) were heated electrically, similar to the 8% in the United States, but much less than the approximately 20% in Norway, where hydroelectricity is the largest single contributor to the total energy supply. Swedish all-electric homes have typical heat losses of two-thirds of the average of oil heated homes considered in Table 7 (17).

In the commercial sector, overall energy use per square meter of space may be as much as 30% lower in Sweden than in the U.S. (16), even before the difference in heating degree-days is considered. The heating intensity, when measured in kWh/m^2-deg-day is approximately 2.5 times lower than in the U.S. We attribute this mainly to the same differences in insulation, ventilation, and construction standards that applied to the residential sector, but further confirmation of the reasons for this difference should be made. The energy consumed in the commercial sector is reduced further by more realistic lighting standards, which also lowers the need for cooling. (Unlike many large buildings in the U.S., Swedish office buildings do not require air conditioning in winter to remove the heat produced by high lighting levels.)

In Table 6 the important residential and commercial uses of electricity are also compared. Higher U.S. energy use arises primarily from a combination of factors: significantly more use of larger appliances like dryers; large "frost-free" refrigerators; excess lighting; and more small applicances (53,54). Air conditioning is conspicuously absent from Swedish electricity use, but accounts in the United States for only 12% of electricity used in the residential and the commercial sectors, and only 3% of our total energy use.

Water heating, another major energy user, requires typically 6200 kWh_t per household in apartments (central water heating) and 10,500 kWh_t per household for single family dwellings in Sweden, while the corresponding U.S. figures are 9,600 kWh_t per apartment and 11,500 kWh_t per single family dwelling. Much of the hot water in Sweden is prepared in centralized systems, eliminating some of the convection and radiation losses of American single unit water heaters. On the

Table 7. Residential space energy consumption (fossil fuels only) and heating efficiencies by climatic regions for the U.S. and Sweden.

	U.S.[a]	Sweden[b]	
		MFD[e]	SFD[d]
Energy Consumption:			
Persons/housing unit	3.3	2.1	3
Rooms/housing unit	5.1	3.2	4.5
Persons/room	0.66	0.66	
Ave. area (m^2)	115	70	110
Degree days (68° F)	5500	9200	
kWh/housing unit	34,000	16,350	28,750
kWh/m^2	300	235	260
kWh/deg-day	6.2	1.77	3.10
kWh/m^2 deg-day	0.054	0.027	0.028
kWh/capita	9150	8200	

Heating Efficiency by Climatic Regions:

	U.S.[e]			Sweden[f]		
	Calif.	Penn.	Minn.	Malmö	Stockholm	Norrbotten
Degree-days (68°F)	1900	5500	8500	7700	9200	13,000
kWh /m^2 deg-day	0.11	0.063	0.049	0.028	0.027	0.026

---

[a] Sources: Refs. (14), (15), (24), and (51). Single family dwelling figures, except kWh/capita, which includes all dwellings.

[b] Sources: Refs. (16), (17), and (53).

[c] Multiple Family Dwelling

[d] Single Family Dwelling

[e] Sources: Refs. (14) and (15).

[f] Sources: Refs. (17), (54). Curves from electricity heated homes were adjusted upward to reflect oil furnace efficiencies and construction.

other hand, the larger systems are not easily metered individually; studies of energy use in apartments in Sweden (16,41) noted that occupants paying individually for heat, hot water and electricity would use at least 15% less than those paying indirectly by sharing cost in the rent. Without detailed studies of water use, however, we cannot conclude anything about the E´.

An important mechanism for supplying space heat in Sweden is with district heating, in which central stations either produce heat alone, or co-generate heat and electricity. District heating supplies 19% of the total residential heat needs in Sweden (16). The energy balance for Swedish thermal power plants shows 24% of the kWh input appears as warm water or steam, primarily for heating of homes and buildings, and 29% of the output is electricity. Figure 6 illustrates the combined electricity-heat system of Malmö, a city of 250,000 (55). The overall effect of these systems, after the slightly lowered production of electricity is taken into account, is a net saving of fuel of 1300 kWh per capita, which is 2% of the total energy consumption in Sweden (see Appendix for further detail).

C. Industrial Energy Use

In both Sweden and the United States the largest use of energy in industry is for basic materials processing. In Sweden this energy use is highly concentrated, five sectors accounting for 85% of the net use (16,21).

In Table 8 we see that larger fractions of Sweden's manufacturing value added and energy use, compared to the U.S., are concentrated in the five energy intensive sectors. Additionally, the energy use in each sector and the value added is more concentrated toward materials processing – organic chemicals versus drugs, paper mills versus paper products, etc. Thus the mix of output in Swedish industry is more energy intensive than in the U.S. This is reflected in the E for the five industries combined, which is higher in Sweden than in the U.S., although total E for all of manufacturing in Sweden is very close to that in the U.S. While some energy intensive products, such as plastics, chemicals, and aluminum, are made in greater quantities in the U.S. than in Sweden, steel, cement, paper and pulp are made in greater amounts in Sweden. Much of Sweden's energy intensive raw output is exported.

However, these measures of intensity can be misleading. As Table 9 shows, the process energy intensities (E´) are signficantly lower in Sweden for virtually every product, usually because of reduced process heat requirements. These findings

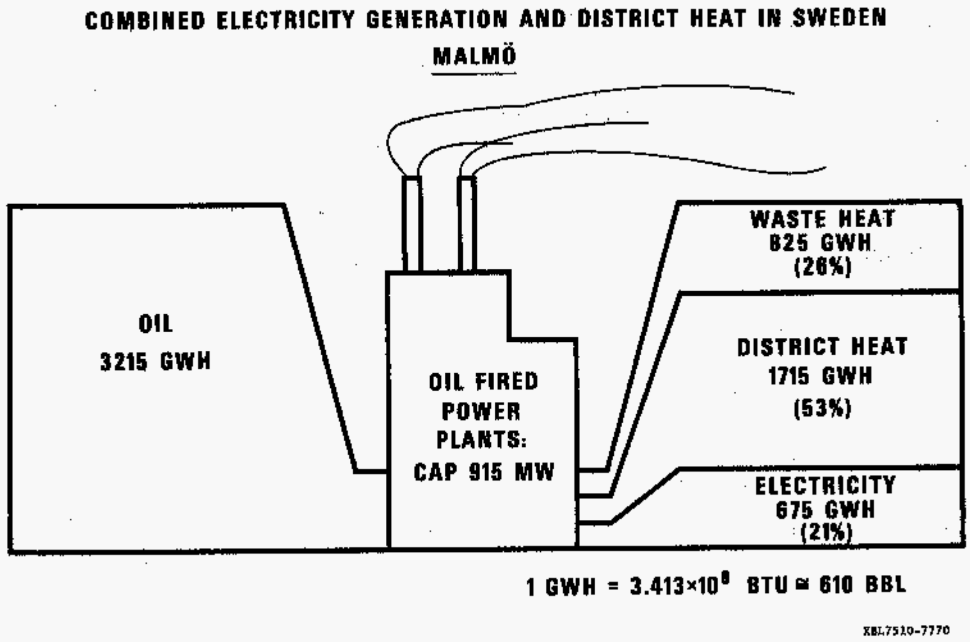


Fig. 6. District heating and electricity co-generation in Malmö, 1973. From (55).

suggest that Sweden's industry is more energy efficient than our own. More important, though, these findings stress the inaccuracy of measuring energy use, or efficiency, by aggregate ratios of energy use to value-added or GNP,as is done in Ref. (1). We note that similar differences in process energy intensities were found in the study of West Germany (11).

Swedish industries use more electricity as a fraction of all energy, or as a fraction of all electricity used in the whole economy, than American counterparts. This effect can be understood by noting that historically nearly all of Sweden's electricity was generated from hydropower, the predominant domestic energy resource; industries could be expected to utilize this resource, which has been less costly than steam electricity. In addition, the ratio of the price of electricity to the price of fuel (for the steel industry in particular) is lower in Sweden than in the U.S. These prices are summarized in Table 10.

The overall comparison of electricity used by industry is shown in Fig. 7. Industrial electricity costs in Sweden are close to those in the U.S., but the dominance of several industries in Sweden that pay less than the U.S. average pulls the average price in Sweden below that in the U.S. (Table 10). Since prices are so similar, we attribute the higher electric intensity (shift to the right in Fig. 7) to the lower ratio of the price of electricity to the price of fuels as compared to the U.S. (Table 10).

Additionally, however, other factors in Sweden tend to reduce specific industrial energy consumption compared to the United States. Sixty percent of all fuel used in the paper industry (which consumed 16% of all energy in Sweden) is provided internally by barks and liquors as opposed to 35% in the U.S. (21), but a third of the electricity used by that industry, and smaller fractions elsewhere, is co-generated with steam production (16,64), thus reducing fuel needs. Some savings through co-generation have been obtained, for example, in Germany (11) and are considered to be economic for the U.S. (65), where half of the electricity consumed in the paper industry is self-generated, but only a small amount is co-generated.

In addition to energy savings in process industries in Sweden, assembly industries there tend to show lower use of fuel per unit of product (or value added) than in the U.S. This comes about in spite of more important space heating requirements compared to the U.S., in some cases surpassing electric drive and lights. A total of 20% of Sweden's industrial use is for space heating. In the entire Volvo concern, encompassing several large assembly plants, 1974

Table 8. Energy use in industry-economic overview[a]

Industry Sectors	SIC	SNI	D_J Value added ($/capita)		E_J (kWh/$)[b]		T_J[b]			
							U.S. (1971)		Sweden (1970)	
			US	Sweden	US (1971)	Sweden (1970)	kWh	kWh_e	kWh	kWh_e
MANUFACTURING										
Paper[c]	26	341	62	112	44	75	3200	290	7625	1300
Market pulp	261	34111	2	34			125	25	3680	500
Paper mills	262,3,-6	34112,-113	24	60			2500	230	3895	800
% of sector[d]			40%	84%			82%	88%	99%	100%
Chemicals	28	351,352	156	84	25	34	3930	575	1135	540
Organic	2815,-18	35111	16	7			1575	110	80	250
Inorganic	2812,-13, -16,-19	35112		9			1220	250	110	100
Plastics, fibers	282	3513	24	18			630	80	305	80
Agricultural	287	3512	8	7			115	15	120	55
% of sector[e]			31%	49%			90%	79%	54%	90%
Feed stocks consumed	*Excluded from totals*						4600		1500	
Petroleum	29	353,-4	30	11.5	142.9	134	4000	145	1540	30
Refining[f]	291	353	25	8	152.0	187.5	3800	135	1500	23
Stone, Glass, Clay	32	36	51	50	36.3	32.5	1850	120	1625	150
Primary metals	33	37	110	103	51.8	37.7	5700	710	3880	910
Basic steel	3312	37101	46	74			4390	190	3065	500
Alloys	3313	37102	10	3			80	35	280	160
Nonferrous	333	37201	8	6			640	300	370	225
% of sector			57%	81%			90%	74%	96%	97%
Total Energy Intensive[g]			421	328	44.4	48.2	18,680	1700	15,800	3000
Other Manufacturing			1320	808	3.4	2.0	4525	1050	1600	710
Total Manufacturing			1741	137	13.3	15.3	23,205	2750	18,100	3710
ENERGY HARVEST (excluding refining, elect.utilities)							2500	230	500	280
MINING							570	100	570	180
AGRICULTURE, FORESTRY							1825	55	510	200
CONSTRUCTION (excluding vehicles)							900	16	650	85
Total Industry (excluding feedstocks)							29,020	3300	19,630	4460

Footnotes for Table 8.

---

[a] Sources: for U.S. Refs. (30), (56), and (57); for Sweden Refs. (16), (33), and (35). kWh_e included in kWh figures.

[b] Net. For gross (kwh_t) multiply by [(2 kWh_e/kWh) + 1] , where the kWh and kWh_e are from T_J. kWh_e is included in the kWh figure. U.S. Figures for kWh_e include self-generation but these are not included in the E_J. U.S. E_J is for 1971; value added from (56) inflated to 1971 values.

[c] Includes wood wastes.

[d] The value added is given for those SIC and SNI groups that are more energy intensive than the average. Percent of sector gives the percent of the sector contained therein. It can be seen that Sweden's value added is more concentrated in these sectors.

[e] Feedstocks for Sweden estimated from Refs. (31), (32), and (33).

[f] Includes captive consumption not counted by most Swedish studies, but found in Refs. (31) and (32). Feedstocks subtracted from refining losses in Ref. (31). 500 kWh/capita of non-fuel petroleum (lubricants, etc.) omitted but counted in Table 2. The Swedish refining T could be as low as 1000.

[g] Excludes self-generation for electricity totals, except 400 kWh self-generation in paper and pulp industries in Sweden.

Table 9. Materials and energy consumption data for the U.S. and Sweden.[a]

	D_J (kg/capita)		E_J (kWh/kg)		E_J (kWh_e/kg)		T_J (kWh/capita)		T_J^* (kWh_t/capita)[c]	
	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden	U.S.	Sweden
Basic steel[d]	580	650	7	4.8	0.5	1.0	4000	3100	4640	4420
Aluminmum[e]	17	9	17.7	17.7	17.0	17.0	300	160	880	465
Oil, refined[f]	2900	1400	1.4	1.1	0.05	0.05	4060	1500	4350	1540
Market pulp[f]	~1	550	9	6.7	1	1	—	3685	—	4900
Paper, inc.[g] pulping	260	550	9.5	6.6	1.5	1.5	2470	3630	2860	4730
Cement	342	460	2.0	1.6	0.1	0.1	685	735	755	830
Organic chemicals[h]	234	89	6.7	4.0	—	—	1575	355	1800	855
Inorganic chemicals[h]	100	87	12.2	4.4	—	—	1220	390	1720	600
Plastics, fibers[h]	51	43	12.3	5.0	—	—	630	215	790	375
Fertilizer[h]	105	67	1.0	1.8	—	—	115	115	145	230
Feedstocks[b] (energy)	480	215	11.63	11.63	—	—	5600	2500	—	—

[a] Sources: For U.S. Refs. (5), (7), (11), (24), (30a), (56), and (59); For Sweden Refs. (7), (16), (23), (32), (33), and (60). 1970 and 1971 data.

[b] Electricity was included (net) in E_J.

[c] T_J for Sweden reflects 3 kWh_t/kWh_e.

[d] We did not include the energy content of scrap, estimated at an average of 500 kWh/ton for the U.S. and 1000 kWh/ton for Sweden, averaged over all steel.

[e] Aluminum counts only the smelting of Al_2O_3 to Al. Refining of bauxite takes place in the U.S., but not in Sweden.

[f] U.S. oil refining E_J taken from Refs. (59) and (56). Swedish losses estimated from Refs. (31) and (33). The latter gives a very low figure of 0.65 kWh/kg, but estimates from the known flow of oil through refineries indicate 1.0 kWh/kg.

[g] Pulp and paper include the energy in wood wastes and liquors. These were as given in Refs. (30a) (59) and amount to 1000 kWh.capita for the U.S. Refs. (21) and (16) give about 4000 kWh.capita for Sweden. Sweden uses more wood waste for fuel per ton of output, and uses fewer external fuels as well. Swedish electricity was 1/3 cogenerated, the U.S. about half that.

[h] Figures for $E_{chemicals}$ are difficult to retrieve and hard to compare. The use of feedstocks, including road oils, was converted to kg by using the approximate relation 1 kg (oil equivalent) = 11.63 kWh. The U.S. enriches the uranium used in Sweden, and the energy is counted in SIC 281, industrial chemicals (See Ref. (57)).

Table 10. Energy intensities and costs in industry.[a]

	T_J (kWh/capita)		E(kWh/$)		P(¢/kWh)		P_e/P_f	
	U.S. (1971)	Sweden (1970)	U.S. (1971)	Sweden (1970)	U.S. (1971)	Sweden (1970)	U.S.	Sweden
Five energy industries (excluding feedstocks)[b]								
Fuel (f)	17,000	12,800	40	39.1	0.15	0.20	5.4	3.5
Electricity (e)	1700	3000	4	9.2	0.81	0.75		
Other manufacturing[c]								
Fuel (f)	3500	900	2.7	1.1	0.19	0.36	6.3	3.1
Electricity (e)	1075	700	0.8	0.9	1.2	1.1		
Total manufacturing								
Fuel (f)	20,500	13,700	12.0	12.0	0.16	0.22	6.0	3.7
Electricity (e)	2775	3700	1.6	3.3	1.0	0.82		

[a] Sources: For U.S. Refs. (56), (57), and (60); for Sweden Ref. (16). Data on price from purchased fuels only. Data on electricity for purchased electricity except for Swedish paper industry.

[b] SIC 26, 28, 29, 32, 33.
SNI 341, 351, 352, 353, 354, 36, 37.

[c] SIC 20-25, 27, 30, 31, 34-39.
SNI 31-33, 342, 355, 356, 38, 39.

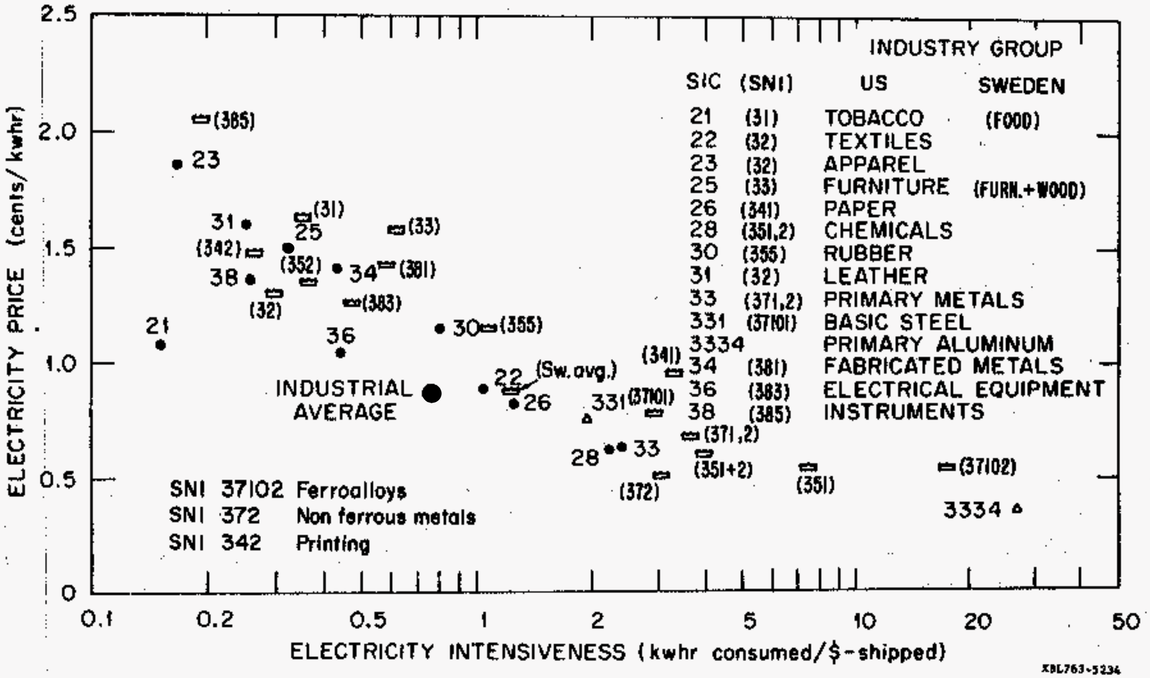


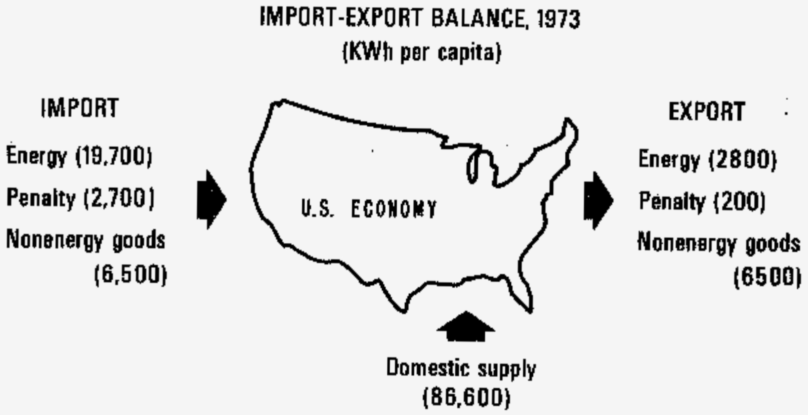
Fig. 7. Electricity intensiveness, ¢/$ shipped, and price. U.S. data from 1967 Census of Manufacturers, assembled by Hirst(58a) shown as dots, triangles; Swedish data (from EPU (16)) shown as crowns. Use includes purchased only. SIC and SNI codes given for identification of similiar industries.

energy use was estimated at 0.6×10^9 kWh for space heat and hot water, a similar amount for process heat, and an equal amount for electricity, of which one third went for lighting and office use. (Volvo was able to cut its total energy use 25% after the oil embargo through "leak plugging") (61). If Swedish industrial fuel use were adjusted for comparison purposes to take into account the difference in climate, usage could be 10% lower.

The relatively more modern equipment in Swedish industry — Sweden's national accounts have grown significantly faster than those of the U.S. as the Swedish GNP approached ours — certainly contributes to the higher efficiency in Sweden, just as the U.S. industry improved energy efficiency through technological change since World War II in spite of falling energy prices (56). Data collected by Meyers *et al* (56), compared with Swedish data (kWh/ton or kWh/$), suggests that Swedish manufacturing energy intensity today lies on Meyers' projected U.S. curves 10 - 15 years hence. Missing from Swedish industrial energy use was (and is) "interrruptible" gas at bargain prices, and cheap coal, two fuels that have been important to many U.S. industries and whose low price and availability fostered higher energy use in the past.

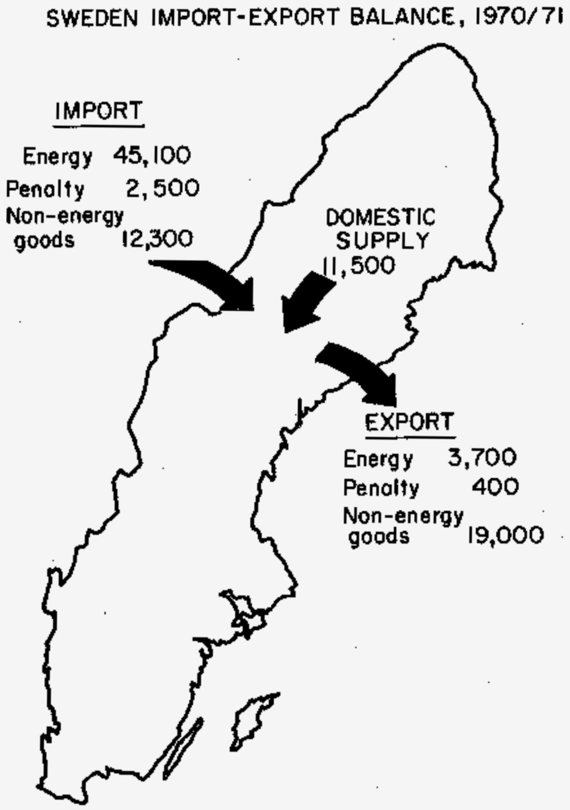
Both official Swedish government forecasts (16) and the views of individuals in industry (61-63) reflect the belief that optimization to ever-increasing fuel prices will further reduce specific energy requirements of Swedish industry toward the end of the century, as many have also predicted for the United States (56). Since Sweden traditionally has paid a high industrial wage, the saving of energy has come about not by direct substitution of labor for energy, but through the substitution of energy management (61) and capital (B. Carlson in Ref. (16)) for energy.

Other factors in resource use in Sweden contribute to both lower demand per product and lower demand for energy intensive products themselves. It was noted above that Swedish autos outlast American counterparts, weigh less, and use materials that themselves require less energy than their American counterparts. Furthermore, Swedish consumers have maintained the widespread use of returnable bottles. Other utilization patterns (relative sizes of D_J) are interesting; in the late 1960's plastic bags became popular, only to be replaced by paper again as the cost of plastic, made from imported petroleum, rose relative to the cost of paper made largely from domestic sources. We can generally conclude that cultural and institutional factors combine with economic and technical factors to effect energy savings in the industrial sector in Sweden relative to the United



XBL763-5271

Fig. 8. Imports and exports of energy via foreign trade, U.S., 1973. "Penalty" refers to process energy embodied in refined fuels. From (35). For 1971, "penalty" in import side scales with imports of refined oil.



XBL762-5128

Fig. 9. Imports and exports of energy via foreign trade, Sweden, 1970. Includes wood wastes, but not the energy content of wood or paper as a fuel. From EPU (16).

United States. This is mainly done by increasing efficiency (lowering the E_j's), but changing the mix of products (mix of D_J's) actually consumed in Sweden toward lower energy intensity is also significant in some areas. In future work we hope to analyze these differences in greater detail.

D. Imports and Exports of Goods

Since imports and exports comprise an important part of economic activity it is important to evaluate the energy embodied in non-energy trade, as well as the process energy embodied in refined fuels, such as gasoline. For the U. S., Herendeen and Bullard (35) found that while non-energy imports and exports contained equal amounts of energy,[‡] the imports of refined oil embodied more energy than exports of coal and refined oil products (excluding the energy actually in these fuels). The balance for 1973, indicated earlier in Table 2 and Fig. 2, is shown in Fig. 8. A similar balance for Sweden, evaluated by EPU (16) was shown in Table 2 and Fig. 3. The complete trade is shown in Fig. 9. It can be seen that the energy embodied in foreign trade affects Sweden – with an export surplus of embodied energy – far more than the U. S., with a small import surplus. An even greater affect was estimated for Denmark by Elbaek (8) who found that the energy balance of trade amounted to an import of 20% of the energy consumed in Denmark. By contrast, West Germany has a large export surplus (11). Note that in every case the imports of *fuels* are much larger than any of these figures. We conclude that an accounting of the energy embodied in foreign trade widens the difference in energy use between Sweden and the U.S.

V. ANALYSIS OF ENERGY DIFFERENCES AND CONCLUSIONS

In Table 11 we show explicitly some important energy prices for Sweden and the U.S. The largest price differences occur in road fuels, even before considering the higher taxes on automobiles in Sweden. Electricity, on the other hand, has been relatively inexpensive (compared to fuel) in Sweden, due to the fact that in the past a large share of electricity has been hydropower (66). In 1971, electricity use in Sweden (7400 kWh per capita) was close

---

[‡] Counting "direct" energy (applied by the producer of a good or service) and "indirect" energy (the energy required to produce the materials and services used by the producer, and so on).

Table 11. Typical energy prices in the U.S. and Sweden. Exchange rate used is \$1 = 5.18 skr (1960-1970) and 4.30 skr (1974).

	U.S.[a]				Sweden[b]			
	1960	1970	1974	*¢/kWh 1970*	1960	1970	1974	*¢/kWh (1970)*
Oil Products (¢/gal):								
Gasoline[c]	30	35	45	*1.04*	53	61	116	*1.82*
Diesel	23	28	35	*0.83*	42	48.8	90	*1.45*
Heating oil-								
Small customers	15	18	35	*0.50*	13.3	13.2	40.6	*0.37*
Large customers	10.5	12	25	*0.33*				
Heavy oil	7	8	23	*0.23*	7	8.5	22.5	*0.24*
Gas (¢/MM Btu):								
Residential	120	130	190	*0.43*	—	550	1973 680	*1.9*
Industrial								
Firm service	75	80	—	*0.27*	—	—		
Interruptable service	40	50	—	*0.17*	—	—		
Coal, Industrial[d]								
(\$/ton):	10	15	25	*0.17*	—	18		*0.2*
Electricity (¢/kWh):								
Base	2.75	2.75	—	*2.75*	3.14	2.12	1975 2.3	—
Base and space heating	1.75	2.0	—	*1.5*	—	~1.5	1975 2.0	
Industrial	1	1	1.5	*(0.4-2.1)*	—	0.93	1975 1.8	*(0.6-2.2)*

[a] Sources: Refs. (15), (24) and (57). Ref. (58) gives following prices *(¢/kWh)* for U.S. industry as a whole in 1971: gas 0.13, coal 0.12, oil 0.23, electricity 0.98, other 0.25. Cf. Swedish prices.

[b] Sources: Refs. (16), (23), (48), and Swedish Embassy press release, 1975.

[c] Swedish gasoline taxes; 42¢/gal in 1970, about 68¢/gal in 1974. U.S. price includes 10-13¢/gal tax.

[d] Coal price excludes captive and utility coal.

[e] Swedish figures based on 1700 *kWh/yr* (1960), 3000 *kWh/yr* (1970), 2000 *kWh/yr* (1974).

to that in the U. S. (7700 KWh per capita), but more of this total was used in the industrial sector in Sweden and more in the residential/commercial sector in the United States. Other fuels in Sweden lie between these two extremes, being slightly more expensive in Sweden (before 1973) and used more efficiently there as well. Since the price of oil used for home heating in Sweden was comparable to U. S. values (until 1973), the length of the heating season, as well as institutional factors mentioned above, must account for the efficient use of that fuel for space comfort. Significantly, however, Sweden had no natural gas or domestic coal, two fuels whose low prices certainly encouraged intensive use in the U. S.

Higher energy prices alone, however, do not account for the more efficient energy use in Sweden. In our report and elsewhere, it has been stressed that while a given set of energy prices determines a mix of energy and other economic factors that allow production for the least cost, institutional and social factors determine how close individual consumers, firms and society as a whole come to this most economic energy use. In the United States, for example, mortgage policies and market considerations constrain developers to minimize first costs, rather than life cycle costs, constraints which do not appear to be applicable to construction in Sweden. We have also seen that building codes have imposed energy conserving construction more uniformly in Sweden. Additionally, the Swedish government has given priority to energy conservation in housing loans. Passenger transport in Sweden has also been strongly influenced toward energy conservation through government policy, in this case mainly through the market mechanism by various taxes and incentives. These factors also encourage important synergistic effects. Good intercity transport, and high costs of operating an automobile, tend to keep the population more concentrated. In addition to maintaining the viability of the public transport system itself, this situation also affects housing and living patterns in energy saving ways. With increased population densities apartment living is more common, allowing potential energy savings through fewer external walls, better insulation and more efficient heating systems. Shopping also becomes easier, with more neighborhood stores; trips are shorter, often on foot, and smaller storage facilities are required, resulting in smaller capacity refrigerators with consequent electricity savings.

In a recent study of energy use in the U. S., Hannon (67) suggested that lowering the energy requirement for an economy by changing lifestyle and the mix of consumer goods (the D_J) would be difficult, because consumer expenditures would generate energy requirements no matter how they were directed. We have shown here that in Sweden the D_J are shifted toward less energy intensive activities, and the E_J toward higher efficiency. For both effects, dollars saved by saving energy in one activity and re-spent on another, do not, on the average, generate as much energy use as expenditures for a more energy intensive mix of D_J, or activities with less efficient E_J, would have done. All energy intensities are reduced through higher efficiencies, i.e., conservation, and shifts from high to low energy intensive activities are made at the same dollar level. Sweden, like other European countries, developed these energy economies to off-set its higher energy prices and balance of payments problem resulting from importing energy. This resulted in a higher standard of living for a given level of energy consumption. This suggests the answer to the dilemma posed by Hannon: in the face of energy scarcity and consequent rising energy prices consumers in the U. S. would seek to maintain their standard of living by optimizing energy use both through increased energy efficiency and through shifting to lower energy intensity activity.

In future work we hope to explore further both the underlying causes of and the mechanisms for achieving higher energy in Sweden. At this time, however, we offer some tentative conclusions about energy use obtained from the U. S. Sweden comparison:

1) For a given level of GNP, efficiency of energy use, climate and the mix of goods and services share in determining the energy requirements of an economy. Efficiency may be the most important factor in the long run and is affected predominantly by energy prices, though institutional and cultural factors play a role in how well energy use responds to energy costs.

2) Projecting energy needs on the basis of past correlations between energy and GNP (or other macro-economic variables) is a very insecure procedure, given both the spread in energy use in countries with a given GNP and the great differences in efficiency, both actual and theoretical, with which individuals and firms use energy to carry out tasks. Conclusions commonly reached about the energy/GNP ratio (1), especially those that purport to show that the U. S. uses energy efficiently (solely on the basis of gross energy use, electricity use, and GNP (68)), are misleading and contradicted by in-depth studies such as our own.

3) No matter how one counts hydropower, it does not account for a major portion of the difference between U.S. and Swedish energy consumption.

4) Adjustments of energy use in the U.S. and Sweden that reflect climate and the energy embodied in foreign trade increase the difference in energy consumption between Sweden and the U.S.

Our international comparison suggests that many energy conservation measures are available to the United States, especially as energy prices continue to rise. The Swedish economy performs well as a (relatively) energy efficient economy, suggesting that more efficient energy use will not interfere with the function of the American economy. While we hesitate to give an exact figure we suggest that Swedish methods of energy conservation, including smaller cars, better structures, and more efficient use of process heat, would result in savings of 30% of the total energy used in the United States (Fig. 10). Thus international energy use comparisons, far from suggesting an inevitable coupling between level of economic activity and energy use, actually suggest ways in which more well being can be wrought from every Btu of fuel and kilowatt-hour of electricity consumed in a given country.

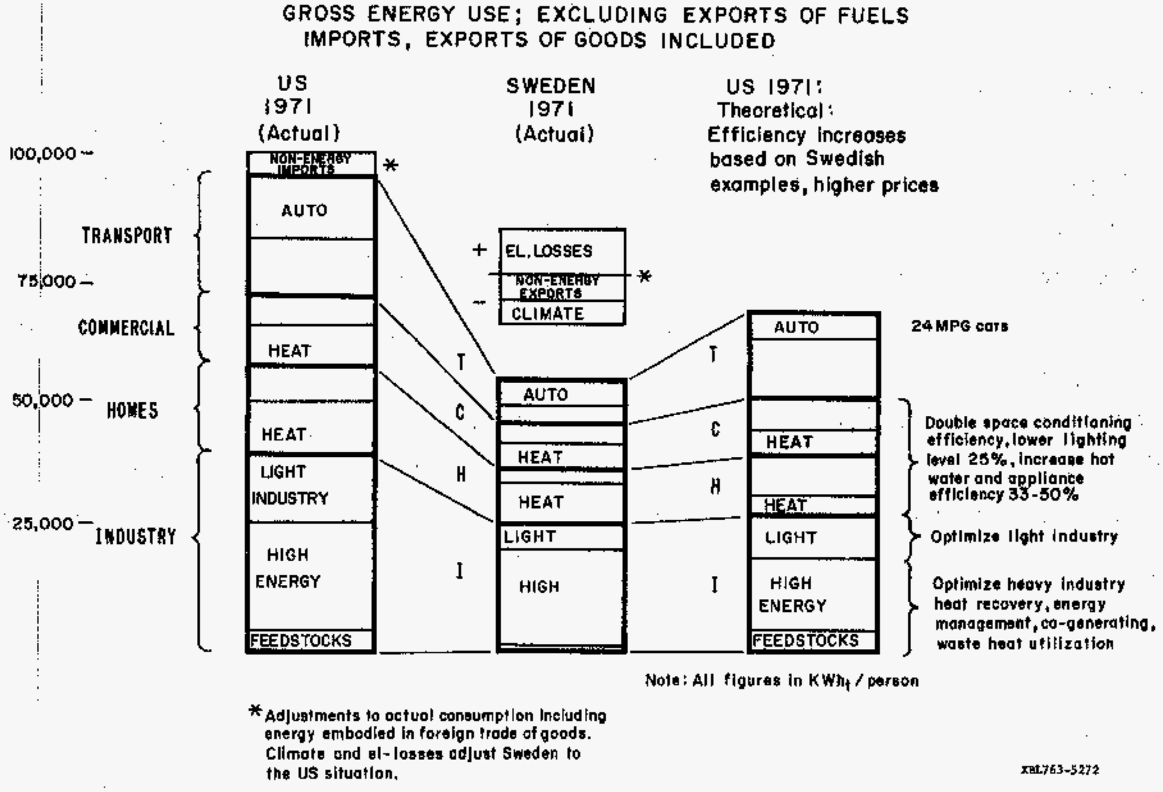


Fig. 10. Summary: U.S. and Swedish energy use, 1971, and U.S. use based on Swedish intensities in industry, space conditioning, autos (mpg); also assumes U. S. Appliance intensity decreases by 33%, lighting levels decrease by 33%. Freight, airlines, energy harvesting ignored, but higher air conditioning and lighting efficiency factored in. See also (3-5). Lifestyle factors (numbers of appliances, passenger miles) not considered.

FOOTNOTES AND REFERENCES

Note: Where a title is listed in English only, it is available in English. Where the listing is in Swedish, it is available only in Swedish.

1. H. R. Linden, Testimony Before the President's Energy Resources Council, Dec. 10, 1974. See also Resource, Economic and Historic Considerations Related to Issue of Energy Policy, 1975. Available from Institute for Gas Technology, Chicago, IL.

2. For a different view of energy and GNP data see D.B. Goldstein and A.R. Rosenfeld, Conservation and Peak Power: Cost and Demand, Lawrence Berkeley Laboratory Report LBL-4438 (1975).

3. M. Ross and R. Williams, Assessing the Potential for Fuel Conservation, Institute for Public Policy Analysis Report 75-02, SUNY, Albany, NY (1975). (Available from M. Ross, Department of Physics, University of Michigan, Ann Arbor, MI.)

4. L. Schipper, "Energy Conservation: Its Nature, Hidden Benefits, Hidden Barriers," Energy Communications (in press, 1976). See also L. Schipper, "Towards More Productive Energy Use," Annual Reviews of Energy, Vol. 1, Annual Reviews, Inc., Palo Alto, CA (1976).

5. A. Makhijani and A. Lichtenberg, "An Assessment of Materials and Energy Utilization in the U.S.," Environment 14 (5):10 (1971).

6. World Alternative Energy Strategies Project, C. Wilson, Director (communicated by S. Carhart and P. Craig, 1975). Also Comparison of Energy Use in Ten Countries, Resources for the Future, Inc., (communicated by J. Darmstadter, Director).

7. A. Doernberg, Comparative Analysis of Energy Use in Sweden and the United States, Brookhaven National Laboratory Report BNL-20539, Upton, NY, (1975).

8. Industri Department, Danmarks Energi Forsyning i Fremtiden (Denmark's Energy Supply in the Future), Kobenhaven (1974). See also B. Elbaek, Energi--Energi--Energi Kris, Munksgaard, Kobenhavn (1975).

9. Ministry of Industry, Energiforsyningen in Norge på Fremtiden (Energy in Norway in the Future), St. Medl. Nr. 100, Oslo (1974). See also H. Parr et al., Energi, Miljø og Samfunn (Energy, Environment, and Society), Norges Naturvernforbund, Oslo (1974).

10. J.D. Parent, Some Comments on Energy Consumption and GNP, Institute for Gas Technology, Chicago, IL (May 1974, revised October 1974).

11. R. Goen and R. White, Comparison of Energy Consumption Between West Germany Germany and the United States, Stanford Research Institute, Menlo Park, CA (1975). Available from GPO.

12. T.D. Mount, L.D. Chapman, and T.J. Tyrrell, Electricity Demand in the United States: An Economic Analysis, Oak Ridge National Laboratory, Report ORNL-NSF-EP-49 (1973). Available from NTIS.

13. W.J. Mead, "Discussion of Dynamic Demand Analysis of Selected Energy Resources by H.S. Houthakker, P.K. Verlager and D.P. Sheehan," Conf. of the Am. Econ. Assoc., New York, NY (1973).

14. Foster Associates, Energy Prices 1960-1970, Ballinger Books, Cambridge, MA (1974).

15. A Pilot Project in Homeowner Energy Conservation, Federal Energy Administration and the American Gas Association, Washington, DC (1974). Available from USGPO.

16. Energi Prognos Kommitéen, Energi, 1985-2000, (Energi Prognos Utredningen [EPU]), Ministry of Industry, Stockholm, Available from Allmanna Forlaget, Stockholm (2 vols.).

17. K. Munther, Energi-Förbrukning i Smahus (Energy Use in Single Family Dwellings), Staten Institut for Byggnadsforskning, Report 58, Stockholm (1974). Available from Svensk Byggtjanst, Stockholm.

18. In this and other examples Swedish useage is adjusted to reflect a 60% fossil-fueled heating (First Law) efficiency.

19. S. Schurr and J. Darmstadter, Energy Use in the U.S. Economy 1850-1970. Resources for the Future, Johns Hopkins University Press, Baltimore, MD (1972).

20. J. Kravis et al., A System of International Comparison of Gross National Product and Purchasing Power, John Hopkins University Press, Baltimore, MD (1975).

21. Effektivare Energi Använding (More Efficient Energy Use), Ingenjörs Vetenskaps Akademin (IVA) Med. 181, Stockholm (1975).

22. Some Facts About Sweden, Skandinaviska Enskilda Banken, Stockholm (1974 - 1975). We use 5.18 skr = $1.00. In 1974 the applicable rate would be approximately 4.30 skr = $1.00.

23. Statistiska Årsboken (Statistical Abstract of Sweden), Statistiska Centralbyran (SCB), Stockholm (1972,-73,-74,-75).

24. 1975 U.S. Statistical Abstract, Department of Commerce, Washington, DC (1975). Available from USGPO.

25. K. Hultgren, Månniskan och Bilsamhallet (People and the Automobile Society), Pan Nordstedts, Stockholm (1974).

26. L. Anell et al., Skallvi Asfaltera Sverige? (Should We Pave Over Sweden?), Pan Nordstedts, Stockholm (1971).

27. We use 68°F as a base temperature for both countries, and we ignore appliance heat loads, etc. This understates heating differences because appliance use is somewhat greater in the U.S., while insolation in Sweden is small compared to nearly all of the U.S. in the winter. Peak could temperatures are not as low in Sweden as in our North Central, North Midwest, Rocky Mountain, and New England States, but average temperatures are comparable, while the Swedish winter is *longer*.

28. W. Dupree and J. West, *United States Energy Through the Year 2000,* Department of the Interior, Washington, DC (1972, updated 1975). Available from GPO.

29. E. Cook, *Study of Energy Futures,* Environmental Design Research Associates, Chapel Hill, NC (1975).

30. R. Knecht and C. Bullard, *Direct Use of Energy in the U.S. Economy,* Center for Advanced Computation Tech. Memo No. 43, University of Illinois, Urbana, IL (1975).

30a. *Patterns of Energy Consumption in the U.S. -- 1968,* Stanford Research Institute, Menlo Park, CA (1972). Available from GPO.

30b. T. Hoffman et al., *Reference Energy Systems,* Brookhaven National Laboratory (1974). Available from NTIS.

31. *Verksamheten* (Activities), Ångpanneföreningen, Stockholm (1971-76).

32. SOS Industri 1970-73 (Sweden's Official Statistics -- Industry), Statistiska Centralbyrån, Stockholm (1972-75).

33. *Energiforskning* (Energy R&D), 5 vols., Energiprogramkommitteen (EPK), *Vol. A, Energin* och Näringslivet (Energy and the Economy), Industridept, Allmänna Förlaget, Stockholm (1974).

34. The latest energy use data for Sweden are published as part of the Energy Conservation Bill in the Parliment: *Energy-Hushållning* (Energy Husbandry), Ministry of Industry, Stockholm (Feb. 1975). See also *Energiförsörjningen 1975-1980,* Rapport av Stateus industri-verk, Stockholm. Available from Allmänna Förlaget.

35. R. Herendeen and C. Bullard, "U.S. Energy Balance of Trace," *Energy Systems* in press (1976).

36. E. Hirst, *Energy Intensiveness of Passenger and Freight Traffic, 1950-1970,* Oak Ridge National Laboratory Report ORNL-NSF-EP-41 (1973). Available from NTIS.

37. *Estimated Motor Vehicle Travel in the United States,* Federal Highway Administration, Washington, DC (1970-75).

38. *Nationwide Personal Transportation Survey,* Federal Highway Administration, Washington, DC (1970). Available from GPO.

39. Project Independence: Energy Conservation; Transportation, Federal Energy Administration, Washington, DC (1974). Available from GPO.

40. Regionala Traffikplanering (Regional Traffic Plan), Ministry of Communications, Stockholm (1972). See also Transporter i Sverige (Transportation in Sweden), Ministry of Communications, Report Dsk 1975:4, Stockholm (1974). And see Fact Sheet of Swedish Transportation, Swedish Institute, New York, NY (1973). Available from Swedish Information Service, 825 3rd Ave, New York, NY 10022.

41. Energi: Beredskap i Kristid (Energy: Preparedness During Crisis), Energi Beredskaps Utredningen (EBU), Department of Commerce, SOU 75:61, Stockholm (1975). Available from Allmänna Förlaget, Stockholm.

42. Automobile Facts and Figures, Motor Vehicle Manufacturers Association, Detroit, MI (1975). See also Motor Vehicles and Energy, Motor Vehicle Manufacturers Association, Detroit, MI (1974).

43. K. Austin and K. Hellman, Passenger Car Fuel Economy, Society of Automotive Engineers, SAE Paper 730790, New York, NY (1973).

44. Motor Traffic in Sweden, AB Bilstatistik, Stockholm (1974075). See also J. Ullén, Bilfakta (Auto Facts), Vol. 28, Jan Ullén AB, Stockholm (1975).

45. See Ref. 33, Vol. C, Transport och Samfardsel (Transportation).

46. Personbilarnas Årliga Körlängd (Yearly Private Car Vehicle-Miles), Statens Vägverk, TÖ 122, Stockholm (1974).

47. J. Austin and K. Hellman, Passenger Car Fuel Economy as Influenced by Trip Length, Society of Automotive Engineers, SAE Paper 750004, New York NY (1975).

48. Oljeåret 1974, (Oil Year 1974), Svensk Esso AB, Stockholm (1975).

49. A. Makhijani and A.J. Lichtenberg, An Assessment of Residential Energy Use in the U.S.A., University of California Engineering Research Laboratory, ERL M-310, Berkeley, CA (1973).

50. J. Moyers, The Value of Thermal Insulation in Residential Construction, Oak Ridge National Laboratory Report ORNL-NSF-EP-9, Oak Ridge, TN (1972). Available from NTIS.

51. Residential and Commercial Energy Use Patterns, 1970-90, Project Independence Task Force Report, Federal Energy Administration, Washington, DC (1974). Additional data from S. Dole of Rand Corporation, J. Moyers of Oak Ridge National Laboratory, and Måns Lönnroth of Secretariat for Future Studies, Stockholm.

52. Indeed, the mortgage law of 1957 gave priority to home builders or buyers who intended to insulate beyond the building code minima. A newer program (1975) enables greater subsidies, direct grants, and local testing programs.

53. Sveriges Elkonsumtion, 1975-1985, (Swedens Electricity Use, 1975-1985), Centrala Drift Ledningen, Stockholm (1972).

54. See Ref. 33, Vol. D, Uppvärmning och Lokal Komfort (Heating and Space Confort).

55. R. Johnson, and L. Bell, Malmö's Powerplants, Industriverket, Malmö, Sweden (1973).

56. J. Meyers et al., Energy Consumption in Manufacturing, Ballinger Books, Cambridge, MA (1975).

57. Census of Manufacturers (Energy Data for 1971), Department of Commerce Washington, DC (1972). Available from GPO.

58. W. Chern, Electricity Demand by Manufacturing Industries in the U.S., Oak Ridge National Laboratory Report (ORNL-NSF-EP-87, Oak Ridge, TN (1975). Available from NTIS.

58a. E. Hirst, Electric Utility Advertising and the Environment, Oak Ridge National Laboratory Report ORNL-NSF-EP-11, Oak Ridge, TN (1972).

59. E.P. Gyftopolous et al., Potential Fuel Effectiveness in Industry, Ballinger Books, Cambridge, MA (1975).

60. S.I. Kaplan, Energy Demand Patterns of Eleven Major Industries, Oak Ridge National Laboratory Report ORNL-TM-4610, Oak Ridge, TN (1974). Available from NTIS.

61. Energy Conservation in Swedish Industry, Swedish Federation of Industries, (Industriförbundets Förlag, Box 5501, 11485 Stockholm (1974).

62. A. Iveroth and B. Helmerson, Industrin och Energi (Industry and Energy), Swedish Federation of Industries, Industriförbundets Förlag, Box 5501, 11485 Stockholm (1974).

63. U. Norhammer, in speeches to various industry groups published in Swedish by Ångpanneföreningen, Stockholm (1975).

64. Catalogues of Back-Pressure (Co-Generation) Systems, with Statistics (in Swedish), Stal-Laval Co. (1975).

65. Energy Industrial Center, Dow Chemical Co. et al., National Science Foundation, Office of Energy R&D, Washington, DC (1975).

66. Swedish government hydropower, producing 75% of the total electricity in Sweden, was financed at commercial interest rates, in contrast to our TVA project.

67. B. Hannon, "Energy Conservation and the Consumer," Science 189 (11 July 1975).

68. F. Felix, "The U.S. Becomes More Energy Efficient," Electrical World (1 December 1975). See also F. Felix, "Greater Use of Electricity Boosts Energy Efficiency," Electrical World (1 November 1975). Felix's results are hard to reproduce, and his "statistics" are carefully scrutinized in an appendix to Ref. 11.

69. J. Holdren, "Energy and Prosperity," Bull. At. Sci. (December 1975).

70. Elförsörjningen 1973, (Electric Energy Supply), Statistiska Centralbyrån, Statistska Meddelanden, Nr. 1, 1974:52, Stockholm (1975).

APPENDIX

DISCUSSION OF ELECTRICITY PRODUCTION AND DISTRICT HEATING

It is often noted that Sweden is rich in hydropower, an energy source that accounted for approximately 14% of all energy and 75% of all electricity produced in 1972. Similarly about 35% of Sweden's fuel-based electricity came from back pressure production. This is accounted in Table A-1.

As the kWh_t per capita total in Table 2 suggests, Sweden's energy use would be higher (by about 20%) if all electricity were generated at the U. S. rate of approximately 3 kWh_t/kWh_e. This Appendix discusses the accounting for hydropower and other statistical difficulties.

Hydropower

Seventy-five percent of Sweden's 1971 electricity supply came from hydropower, Sweden's most important domestic energy source, counted in Swedish statistics (Fig. 3) at 85% First Law efficiency. Since most of Sweden's hydro resources are in the far north, transmission line losses are greater than in the U. S., per net kWh_e sold.

But simply tripling the *net* sales of hydropower to final demand, as was done in the kWh_t per capita column in Table 2, can be misleading. This is because the use of electricity, particularly in industry, is stimulated by the low ratio of the price of electricity to the price of fuel.This is, electricity in Sweden cost approximately 0.8¢/kWh to heavy users, while fuel oil cost $0.80 to 1.00/$10^6$ Btu (about 0.3¢/kWh), significantly higher than the price of natural gas or coal to most U. S. industries. Had electricity been 85% thermally generated, as in the U. S., it would have been more expensive, especially since public (as well as private) power is financed in Sweden at prevailing commercial interest rates. Thus we find that electricity utilization in industry and transportation is greater in Sweden than in the U. S., in part because of its low price relative to fuel.

Back Pressure Generation of Electricity

Combined heat/electricity systems in Sweden produce more useful kWh per kWh_t consumed than purely electrical-thermal plants. In 1971 Sweden consumed fuel amounting to about 4.11 MWh per capita to produce 1.77 MWh per capita of

Table A-1. Electric power and heat supply in Sweden (1972).[a]

Sources	Installed capacity (kW$_e$/capita)	Fuel used MWh$_t$/capita	Electric production (MWh$_e$)	Heat production (MWh$_t$)	Efficiency (elect heat/fuel)[b]	Savings (MWh$_t$)
Community back pressure	0.097	1.15	0.34	0.64	0.85	0.87
Industrial back pressure	0.155	0.82	0.33	0.26	0.72	0.49[d]
Electricity only plants	0.48	4.01	1.43	——	0.36	——
Total electricity only	0.79	4.89	2.11	——	0.44	——
Total including heat	——	5.94	2.11	0.90	0.51	1.47
Heat centrals	(0.55kW$_t$)	1.10	——	0.87	0.80	0.35
Total	——	7.09[f]	2.11	1.78[f]	0.56	1.71
Hydropower	1.39	(17.81)[g]	6.59	——	0.85	11.22
Transmission losses			-0.86			
Net import			0.16			
Grand total	2.18	15.0 (25.72)[g]	8.00			

---

[a] Sources: Refs. (16), (21), (31), (64), and (70).

[b] "Efficiencies" are taken from above references, and are used to allocate heat losses in "mixed" systems.

[c] Savings = fuel that would be consumed for electricity only (37% efficiency) plus heat in apartments (60% efficiency) plus 5% of electricity as incremental distribution losses minus actual consumption.

[d] Savings: same as (c) above, industrial boilers estimated 70% efficient. Excludes some generation in paper industry.

[e] Savings = fuel that would have been consumed in apartment boilers (60% efficient) minus fuel actually consumed in centrals. Pipeline losses are small.

[f] Totals do not agree strictly with Fig. A-1 due to different years and accounting for industrial backpressure heat, which is missing from Fig. A-1 and Fig. 3 in the text.

[g] If all net hydropower had been made in a thermal-only power plant (third row) at 37% efficiency. At actual heat rate in Sweden (7), this energy consumed would have been 14.98 MWh$_t$.

electricity, for a "heat" rate of 2.12 kWh_t per kWh_e. This is illustrated in Fig. A-1, in which 0.8 MWh per capita heat-only production is included with about 0.95 MWh per capita included in inputs and about 0.15 MWh per capita in the waste heat figure. If the heat and electricity had been generated separately, about 1.3 MWh per capita additional fuel would have been required, assuming the heat was then produced in central plants, and about 1.5 MWh per capita more if heat had been made in smaller boilers. In fact, half of the back pressure production took place in or near cities, while the other half was located in industries, primarily paper. The heat from these plants is omitted from Fig. A-1.

A combined district heat system is shown in Fig. 6 serving 50% of the needs of Malmö. It can be seen that the utilization of fuel is increased significantly. Swedish statistics (see EPU (16), p. 70) count the efficiency of electricity production as [electricity produced/(total energy consumed - heat used directly/.85)], giving about 78%.

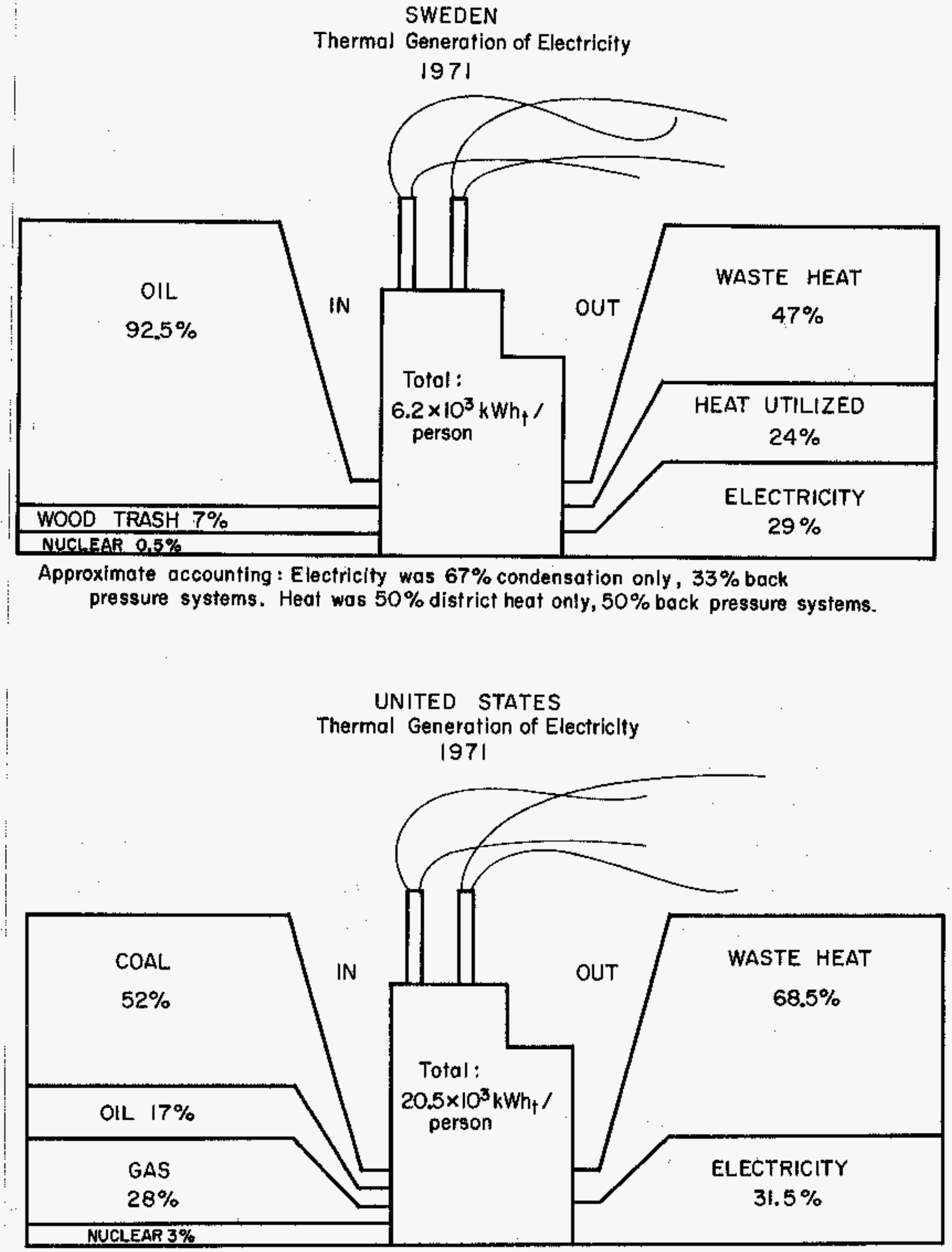
District Heating

The effect of central heat-only plants is included in Fig. A-1; these provide heat for 600,000 dwellings, at 85% fuel to home (First Law) efficiency, compared to 65% for boilers in apartments. This saves 5100 kWh per dwelling or 375 kWh per capita. Another 25 kWh per capita is saved by district heating of buildings, for a total savings of about 400 kWh per capita from heat centrals. These savings must be added to those from use of district heat from combined generation.

The Heat Rate in Sweden

Virtually all of Sweden's thermal-electric-only capacity (1.80 kW per capita in 1972) was built after 1955; thermal efficiencies average 37% versus 32% in the U.S. Since co-generation accounted for nearly 35% of Sweden's thermal generation of electricity in 1972, and since that fraction may remain large during the next decade (63) the "correct" heat rate for Sweden may be imputed to be

[(fuel consumed in electricity-only stations)
+(fuel consumed in co-generation of electricity and heat)
-(total fuel that would have been required if the
heat generated had been produced in heat-only boilers)]
÷[electricity produced].



Approximate accounting: Electricity was 67% condensation only, 33% back pressure systems. Heat was 50% district heat only, 50% back pressure systems.

XBL763-5232

Fig. A-1. The use of fuel to produce electricity in Sweden and the U.S. 1971. Taken from Figs. 2 and 3 in the text. Swedish data excludes some process heat supplied to paper and mining industries (500 kWh per capita). U.S. data excludes a small amount of co- and self-generation in industry. Table A-1 presents a more detailed accounting for Sweden.

This accounting method gives a heat rate of 2.1 - 2.3 kWh_t/kWh_e depending on how one rates the production of heat. Under this scheme the totals given in Table 2 could be modified so that $kWh_t = (kWh - kWh_e) + 2.1(kWh_e)$. Applying the U.S. heat rate to Swedish hydropower, as was done in Table 2 (kWh_t) raised apparent consumption of energy in Sweden by nearly 20%. Applying the actual thermal heat rate in Sweden derived herein would reduce this increase to about 12%. In any case, the differences in energy use between Sweden and the U.S. still remain significant.