Title
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Publication Date
1978-09-01

Presented at the Conference on Impacts and Risks of Energy Strategies, Beijer Institute, Royal Swedish Academy of Sciences, Stockholm, September 1978, and the Environmental Secretariate, Organization for Economic Cooperation and Development, Paris, October 1978.

Energy and Environment Division

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September 1978

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Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

LBL-7882 c.1

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ENERGY CONSERVATION, THE ENVIRONMENT, AND NATIONAL GOALS

The policy discussion following the Oil Embargo was clouded with fears of a return to a primitive existence based on drastically reduced energy inputs to society, or, on the other hand, an abandoning of environmental goals, allegedly a major barrier to development of new energy supplies. Often the energy use associated with environmental improvements was cited as a reason for expanding energy supplies, as if to say that a conflict existed between a clean environment and reductions in energy use. Or it was argued that a relaxation of environmental goals would lower the direct costs of harvesting and using energy and thereby aleviate the need for energy conservation. It has also been argued that the geopolitics of energy alone will force us to substitute riskier or "dirtier" energy sources for relatively clean oil and gas.

Indeed there is no question that the relationship among energy, the environment and economic well-being is complicated. This essay will sort out many of the confusing aspects in order to show how goals relating to the efficient use of energy are aligned both with traditional economic goals and with modern environmental goals. To do this we will analyze in depth the role of energy in the economy and, using examples, trace the origins of many of the misconceptions about that role--misconceptions that have inhibited a profound discussion of energy related goals.

I. ENERGY, THE ECONOMY, AND THE ENVIRONMENT

It is well known that energy is the key resource that allows economic activity (Box 1). The present-day limits on energy use, however, are technological and economic, not natural. We have not yet approached even remotely the thermodynamic limits on the minimum amounts of energy to perform every task. Energy, while thermodynamically a unique resource, is only one of many economic resources that include labor, capital, land, know-how (or information), and the environment, which acts as a sink for the wastes or residuals from economic activity. Since the goal of most economic societies is to produce goods and services that lead to well being at minimum resource cost, minimizing the use of energy alone (or, for that matter, of the environment) is in itself not necessarily an interesting or worthy goal. Given prices for all resources inputs (costs and benefits) producers (or consumers) will in general seek to maximize their private profits (or minimize their costs) in order to produce a consume a mix of goods and services.

As Professor John Holdren's excellent diagram shows (Fig. 1), the energy-environment contribution to the economy possesses two sides. Energy, combined with other resources, produces tangible economic benefits (the left side), but its harvesting and use is intimately connected with disbenefits called environmental pollution (right side). As Professor Holdren has often pointed out, much of the environmental controversy can be traced to two kinds of questions:

1) Qualitative: How are we dependent upon nature's free environmental services for food, economic activity, and health (i.e., the natural ecosystem) as well as for aesthetic reasons (the cultural ecosystem)?

2. Quantitative: What are the economic, social, and health costs of using the environment as a resourcee today, and what are the means available to reduce these costs?

The environmental debate centers both on the interpretation of quantitative (through often uncertain--see Ehrlich et al, Schneider) findings about our intervention with the ecosystem as well as the proocess of charging for the environment as a resource. As Professor Holdren asks, "At what point do the marginal benefits from an increment of energy and associated resource use fall below the incremental environmental costs of that activity?" For a society seeking to maximize its well-being would strive to price all inputs, including the cost of using the environment, so that individual firms and consumers, making rational economic decisions would choose the mix of resources that maximizes well-being <u>including</u> environmental values.

Civilization's flows of energy, intimately connected to disturbed land and water, released heat, processed materials, and transportation, often rival natural flows. It is often possible to place man's use of energy at the center of most environmental disturbance. This does not mean that energy use per se is bad, only that energy flows are intimately bound up in environmental disruption. Seeking to reduce environmental costs per unit of economic activity often becomes synonomous with reducing environmental costs per unit of energy use. If we could improve the combustion of coal, then many factories would produce less smoke, sulfuric oxides and ash for a unit of output; if we could improve the utilization of the heat from the combustion of coal, then less coal would be used ab initio to produce output. Taken together then, these two strategies would allow us to increase the ratio of "goods" (well-being) to "bads" (pollution).

It is alleged, however, that many conflicts arise when one treats energy and environment together. What if reducing pollution tends to increase energy use? What if conservation calls for ending uses of energy that reduced pollution? Suppose that conservation calls for substituting a fuel with greater environmental impact for one with lesser? Suppose that strategies that reduce energy requirements for activities lead to new environmental problems? These are all facets of the energy-environment problem that we shall explore herein. We will in fact show that much of the alleged conflict arises out of the imprecision with which our energy related policy goals are stated, while additional misunderstanding arises out of unfamiliarity with prospects for using less energy per unit of activity. The latter, often called energy conservation, deserves special attention.

II. ENERGY-RELATED GOALS

A glance at the forewords of energy policy documents from any country reveals many elements and goals common to the programs of all countries. Among these are usually

1) reliability of energy supplies at reasonable cost,

2) effective use of available energy supplies,

3) provision of funds for research into new energy supplies and new ways to use energy more effectively.

Of course these broad, imprecise policy goals could well apply to any resource--heat, chromium, water, or widgets. What distinguishes energy policy from other policies are two often-cited problems germane to today's energy system: First, a large part of today's low cost reserves of fuels lie in a few countries that have formed an oil cartel. Second, changes in the energy system tend to take decades, because energy supply and use technologies reach intimately into nearly every corner of economic activity. Were we only concerned with a long term orderly transition from one kind of fuel (non-renewable fossil fuels) to another (nuclear- or solar-based sources of work and heat) our problem might not be different than resource problems faced continually by society.

The geopolitical element, however, makes our work difficult. This is because it is difficult to measure the economic or political value of reducing imports of oil or gas from OPEC countries in the face of alleged political threats or balance of payments problems, real as these problems are. What is it worth economically to reduce the importation of oil (by one million barrels per day) beyond the monetary reduction in the bill for imported oil? While no one has answered this question directly, states have nevertheless proceeded to form alliances (such as the IEA) and declare collectively and as individual nations that they shall try to reduce the imports of oil beyond what might occur "naturally" as a result of market forces. This political goal has generated much interest in the substitution of coal, nuclear, or solar-based technologies for oil and gas, as well as in the more effective use of energy.

Thus Denmark has indicated a great interest in expanding its use of natural gas as an alternative to oil imports, Germany wants to expand its district heating system to save imported oil, France wishes to expand its use of nuclear-based electricity, the U. S. wants to convert industry to coal, and Sweden hopes to limit total growth in energy use, largely through conservation, all in attempts to reduce the importation of oil. Are these worthy goals? That question is very difficult to answer anywhere. Needless to say, these goals are different from the traditional goals of economic growth and (to a certain extent) distributional equity, which often characterize the economic policies of the governments of wealthy nations.

Yet these goals have led to a whole new measuring stick for evaluation of energy systems. Instead of asking whether particular strategies for energy supply or systems of energy use are economically efficient, politically acceptable, and environmentally tolerable, given all costs and benefits, governments ask whether particular activities or technologies will increase or decrease the importation of oil. Measuring sticks for "progress" among the IEA and associated countries are almost entirely restricted to measures of total energy use (or the energy-GDP ratio) and the absolute or relative level of imported energy. Concern over these quantities may be legitimate in its own right, but such concern leads as well to decisions that may cost more than they are worth--substitution of polluting coal-burning district heating for relatively clean individually fired natural gas or oil systems, replacement of relatively low cost oil and gas combustion by higher cost electric heating, and abandonment of or postponement of environmental goals that require increased oil or gas use, in the short run, for their attainment.

Herein lies the source of one "conflict" between energy and the environment. Since national policy calls for a move away from oil and gas, strategies that rely on these fuels because of their relative cleanliness vis a vis coal may be seen as counterproductive. Technical fixes that require increases in the use of these fuels for environmental reasons, such as certain auto exhaust emission devices, are also viewed as counterproductive. Conversely, energy conservation targets (see below) that call for reductions in energy use per unit output of activities are seen as opposing the use of energy for environmental clean-up, which may raise the energy intensity of a particular activity by a few percent. Even before we quantify these concerns we can see that because policy is related to measuring sticks that focus on only part of the energy-economy-environment relationship, the use of imported energy, conflicts are built into policy goals. Ultimately we should judge environmental strategies on their overall costs and benefits, not relying too heavily on energy costs alone.

III. THE LOGIC OF CONSERVATION

Conservation has suffered from several years of misunderstanding (see Schipper, 1976) at the hands of energy producers, government energy policy planners and even some "conservationists" (see for example Schipper and Darmstadter, 1978). Recall that energy is but one of many resources used in economic activity. If economic efficiency is a criterion for resource allocation then changes in energy use might take place if

- Substituting other resources (most notably capital, but also possibly information, materials, land, or labor) reduces the aggregate costs of using resources. Technologies react to changes in energy prices.
- Reducing energy intensities of existing consumer behavior (or production processes through maintenance) results in perceived or calculated benefits (lower fuel bills) greater than perceived or calculated costs (somewhat cooler indoors in winter, a few extra minutes taken to draw curtains at night). Behavior reacts to energy prices.

To an economist the first change represents an alteration in the way a certain output or amenity is produced, while the second change reduces the consumption of certain energy intensive amenities. Engineering economists have studied the role of substitution in reducing energy use, while behavioral economists and others have begun to understand the relationship between energy use and consumer satisfaction that is key to the second change. Essential to predicting how much substitution might take place or how much energy use might be foregone for activities such as comfort is information about the relative price of energy.

In the longer run, changes in the fundamental composition of national output can affect energy use. Some activities, such as production of raw steel, driving, space heating, airplane vacations, consumption of heavy chemicals or throwaway packaging, require greater use of energy per dollar of GNP than do production of calculators, consumption and use of hi-fi equipment, medical services, jogging suits, or home gardening. Changes in the composition of output, or structural changes, can obviously affect total energy use, since, representing each economic activity (in dollars) by O_J, and its energy intensity by I_J, total energy use can be seen to be

$$T = \sum O \cdot I$$

over all uses. The size of T can be determined either by variations in I_J or in O_J. The first kinds of changes in energy use, which reduce I, are commonly referred to as conservation through technical or short term behavior change. But as lifestyles, economies, culture and cultural values change, the makeup of output will also in general change. Changes may be policy-driven--gains on certain products or activities, taxes on certain resources, or tax reduction on others.

In particular, people today seem to want to live farther from work, travel to work by auto, live in detached single family dwellings, and let appliances perform menial tasks as rising incomes permit. These changes, with which we are all familiar, represent the "modern way of living" using energy. Use of autos, of course, has profound environmental impacts. In Europe, since World War II, these uses for energy have grown considerably faster than in North America, where levels were already considerably higher. It would be unfair to label such uses for energy wasteful, but it would be important to investigate whether alternative patterns of consumption and settlement in the future might moderate the utility of some of these amenities, particularly transportation. Moreover, it is important to judge whether saturation of the important energy intensive activities--comfort, hot water, major appliances will occur such that marginal income might then be spent on less energy-intensive activities.

While structural changes toward or away from energy intensive preferences have important consequences for total energy use, they doubtlessly occur less out of a concern (or lack of concern) over energy and the environment than from changing technologies, values, and economic conditions. We will avoid labelling structural changes as "conserving" or "wasteful," but we should be aware of the energy or environmental implications of such changes, particularly where changes are stimulated by government policies.

What is the motivation for conservation? In our view the overwhelming drive will be that of <u>private</u> economic goals. To users, conserving energy means reducing costs. Increases in energy prices, whether from cartel-like activity, natural scarcity, or internalization of environmental costs, should be viewed as exogenous stimuli--the response by energy users is conservation. The extent of the coupling between higher prices and reduced intensities--i.e., the elasticity of energy use, is under intense debate (see below) but all agree that energy use is flexible, given time and changes in relative prices. We allow, however, for social goals that embody conservation. Moreover, society often supplements market forces with restrictions or standards to achieve energy or environment-related goals.

It is important to measure changes in energy use correctly. Measuring performance as changes in the Energy/GDP ratio or sectoral energy/GDP ratios is extremely misleading because structural changes, climate, the possible substitution of one form of energy for another, and demographic factors (such as population density) are all confused with the individual intensities of energy use when aggregates are used. Unfortunately most OECD governments and the OECD itself rely primarily on this measuring stick, by tradition or out of a lack of more detailed data.

When intensities of activities are carefully separated from levels of activity, such that the major components of energy use (see the breakdown in WAES or Schipper and Lichtenberg) become clear, then the changes in intensities can be used to give a good indication of the progress of energy conservation strategies. In the event an environmental strategy increases the intensity of use, that can be indicated as well (see Box 2). Once energy use and intensities are thoughtfully analyzed, the prospects for energy conservation can be meaningfully discussed. Several national studies have appeared that clearly indicate that nations face a wide variety of energy futures depending on the price of energy and policies connected with the implementation of conservation strategies (Table 1). Studies in Sweden, Denmark, and the U. S. have been very specific in suggesting relative energy uses and intensities in the future and how these intensities will be lowered by the variety of technical or behavioral means.

What are some of the more interesting energy-saving technologies and their environmental impacts? We can break down energy use into the traditional categories (buildings, transportation, industry) and select a few examples. Characteristic of nearly all conservation technologies is the substitution of a stock (capital) for a flow. Not only do dollars of capital substitute for greater numbers of (discounted) dollars of energy, physical capital usually appears as part of the energy-saving device, either as mechanical systems, increased heat transfer surface, increased insulation, or, in perhaps the most modern example, use of solid-state devices for information processing to control energy use.

1. Buildings

The most important energy-saving techniques in buildings include reducing heat losses by insulation, reducing infiltration by tighter construction, reducing heat losses by heat-exchanger devices, reducing losses through windows and doors by use of extra glass or wood covers. Insulation will also be applied to heat distribution devices, and heat production devices themselves will deliver more useful heat to the heat distribution system per unit of heat contained in fuel.

Of these strategies, insulation and doubling of glass and door thicknesses represent the greatest increase in materials, the amount of materials used incrementally for tighter construction or better combusters being small. Typically a house might have a wall area of 350 m^2 and a floor and roof area of 2 x 130 m^2. Applying 15 cm thick of fiberglass insulation to the entire shell requires a volume of ~60 m^3 of material (mostly air and very light), reducing the yearly oil consumption from perhaps 4 m^3 to 2 m^3. Since insulation has far smaller density than oil, the flow of materials through the house itself is thus reduced considerably over the lifetime of the insulation, which is typically several decades. While we cannot here compare exactly the impact of air pollution from insulation manufacturing with the impact of air and water pollution from oil production and refining or natural gas production, the immense reduction in amounts of materials required suggests that the <u>production</u> of the conservation technology will pollute far less than the production and comsumption of the fuel saved. Of course the "consumption" of conservation produces no pollution, while the consumption of any fuel produces air pollution at the point of combustion (conversion in the case of fossil-fueled electricity). Thus the substitution of a conservation for energy allows drastic reduction in the pollution from flows of energy and materials.

A further example makes this point even more dramatically. The Tennessee Valley Authority in the U. S. A. pointed out during a campaign to sell heat pumps over electric resistance heat that use of such a device would reduce the burning of coal for electricity by several tons per year. The heat pump typically weighs several hundred kilograms, made up mostly of steel, aluminum, copper, and plastic. Assuming (as in the case of an automobile) that roughly a ton of fuel is consumed to make a ton of heat pump, the incremental energy and materials required to cut electric heating use roughly in half is about balanced by a few years' cumulative savings in coal not produced or burned.

Additional environmental benefits can be included in the evaluation of important conservation strategies. When homes are tightened to minimize involuntary infiltration, the amount of dust and noise disturbing the occupants decreases. The furnace or heating element cycles less frequently, leaving temperatures somewhat more even, and the temperature distribution in space is more uniform, increasing comfort.

2. Industry

In industrial applications the requirements for energy per unit of output have steadily decreased in most applications in most countries. Carlsson's data for cement in the U. S., Sweden and W. Germany (Fig. 2) are typical. Similar gains in energy economy have occurred in the steel and other energy intensive industries. At the same time productivity of labor has increased through mechanization, introduction of new technologies or improvement of existing technologies. In nearly every case newer technologies tend to pollute less than the older ones they replace, especially as anti-pollution devices are incorporated into new processes rather than being tacked on to existing ones. "Clean" tends to accompany conservation in the long run.

Obviously some important energy conserving steps require extra materials, most notably piping, insulation, and increased areas for heat transfer. Other improvements merely require know-how and new design, especially when computer technology is added to improve the running of existing plants.

A good example is the Honakaa sugar mill on the island of Hawaii. There, 950,000 tons/yr of sugar cane are processed, with nearly all the process heat, steam, electric drive and crushing power provided by the burning of bagasse, the residue from the cane. Years ago the bagasse was dumped in the ocean. A new computer scheduled to go on line in late 1978 will lower energy requirements by fine tuning the flow of material in the mill, and an additional recovery boiler will provide ample electric power to be sold to the Hawaii grid. Much of the process water is cleaned and recycled, at a small energy cost. Overall the plant has been turned from a source of water and land pollution (from the wastes) and SO_2 (from burning of oil) into a net energy producer with little residual entering the environment. This factory exemplified the "non-waste technology," a concept that illustrates the principle that ultimately technology and planning should allow us to minimize pollution, energy, and production costs simultaneously, rather than being forced to sacrifice one or two for the other(s). A second example, the "Rapson" process for Kraft paper, is shown quantitatively in Table 2. It can be seen that this process reduces all stresses in addition to increasing productivity. This "Non-Waste" technology illustrates once more how energy conservation and a clean environment complement each other.

In industry, as in buildings, the amount of materials typically required to achieve energy savings is small compared with the throughput of energy saved during the first few years of operation of the system. More efficient processes also reduce the amount of pollution that affects workers.

Carefully matching the size of ports in heat treating facilities to the size of the load, and timing the opening of the doors to the precise arrival of the charge (achieved by computers) reduces heat losses and exposes the workers present to less high temperature heat and emissions from ovens or furnaces. Capture of exhaust gases for purposes of cleaning also allows heat, as well as chemical or particulate pollutants to be removed, and the heat can be "recycled" for preheating of materials, or heating of structures in colder climates (see Boxes 3 and 4).

Two factories in Sweden engaged in welding, for example, found that by capturing indoor pollution at the source, i.e., over each welding system, the air could be cleansed and heat could be recovered before the pollution was able to cloud the whole factory. This case is typical, illustrating how heat recovery and air cleaning complement each other.

The gains in limiting emissions are manifold. First, indoor air is improved. Second, less pollution is emitted to the outside, since the collected air is filtered. Less oil is burned to keep the indoors warm, resulting in a further reduction in emissions. Finally, greater control over the indoor spread of pollution allows the factory to control and possibly lower the overall ventilation rate, saving additional energy and reducing combustion requirements further.

The ultimate marriage of conservation and pollution control may well be the cement-making process. Today large dry kilns are replacing older wet kilns in almost every country. The newer systems use far less heat, often as little as 1/3 less than those they replace. Because the limestone in the cement has an affinity for sulfur the potential hazard from burning oil or coal to provide process heat is reduced considerably, although initially it was the control of these impurities found in some fuels that led to difficulties in adopting the dry process, especially in the United States. Now sharply increased fuel prices as well as the politically motivated shift to coal, have stimulated building of new dry kilns. The gains in energy conservation and environmental quality will be marked.

3. Transportation

Economies in energy use in transportation fall into two well-defined areas--improved technologies, including lighter, more efficient vehicles--and changes in transportation patterns--structural charge. More efficient vehicles promise great gains in air, truck, and auto transportation, the important contributors to air pollution. It need not be recalled that the replacement of coal-burning locomotives in the 1950's and 1960's by diesel and electric vehicles brought about a great energy saving as well as a reduction in pollution, both to the areas adjacent to railways and to the passengers themselves.

While the reduction of the size of autos now occurring in the U. S. and Canada will allow significant energy savings, evidence suggests that the energy required for controlling pollution, as a fraction of all fuel burned in a auto, will also be reduced. This is discussed more fully below, but we point in passing to the double savings in gasoline. Greater use of diesel autos, while possibly increasing noise and odors somewhat, will reduce the production of the more notorious NO_x and CO considerably. In the case of North America, a great potential exists for substituting light diesel powered trucks for the existing fleet of Otto engine trucks. One study found that short haul freight required nearly 3 times more fuel per ton-mile in the U. S. than in Sweden, attributing a great deal of this difference to the predominance of small 4-cyclinder conventional vehicles and diesels in Sweden.

Short haul jet passenger aircraft also show great potential for energy savings, as the European Airbus and its American competitors, scheduled to appear in the early 1980's, reduce considerably the energy cost per seat mile of flights in the 500-2000 km distance class. This reduces resulting pollution not only by reducing emissions per mile, but also by reducing the number of aircraft in the air (compared to using smaller DC9,737, Caravel or Trident aircraft). Air control and ground handling problems can be reduced somewhat, allowing shorter waiting times on the ground (with engines running) and in the air, reducing air pollution in the vicinity of airports.

Of course improved rail service between close-by city pairs, as in Germany, could limit the number of short stage-length flights (say under 200 km) where fuel economy is low. The competition between air, rail, and auto in Central Europe and the Northeaster U. S. is intense, but rail seems hard put to match the growth of the other two. This means that even as autos and aircraft become individually less polluting and more energy efficient they will increase their importance even further relative to the train, which uses considerably less energy and tends to pollute less. This enigma, while understandable when the value of time or convenience is included along with energy, points to a difficult area for transportation policy: How heavily should governments weigh the environmental qualities of various transportation forms in their distribution of subsidies or support of infrastructure--roads, airports, rail rights-of-way?

This difficult question leads us directly to discuss the possibilities for saving energy by structural changes in the amount of travel consumed or the choice of modes. Clearly auto ownership in North America is close to saturation, intermediate in Sweden and New Zealand, but unsaturated elsewhere in the OECD (Table 3). Comparing the U. S. and Sweden, short intra-city trips are far more prevalent in the U. S., accounting for a dramatic part of the difference in auto use and total miles driven between the two countries. These short trips, especially in congested areas, consume the most fuel per mile and produce the most pollution. Yet Swedish and other European driving patterns are slowly moving toward those in place in America. Increases in vehicles, vehicle miles, and the energy intensity of the driving cycle will offset some of the gains made through more efficient technologies. This will aggravate air quality as well. Should governments intervene to increase energy savings?

The question is difficult to answer, given the political difficulties of limiting use of autos. But when environment, energy, congestion, auto safety, and the scarcity of land for streets and parking are taken together, the body politic may decide that rather direct measures are needed to limit the use of autos in congested areas. Such measures might include

a) tolls to enter downtown, combined with very high parking fees (Stockholm has the latter and has considered the former),

b) severe limitations on any on-street parking (Stockholm; San Diego, California),

c) barriers and other traffic-routing mechanisms and built-in inconveniences (Stockholm; Berkeley, California),

d) out-right ban on traffic, excepting taxies, busses, and delivery vehicles,

e) selective ban, perhaps on all fueled vehicles, allowing only electric vehicles.

These strategies are aimed both at reducing traffic into congested city centers, reducing combustion emission, and at reducing traffic around these areas. They may become inevitable as automobile populations swell in Europe. They would ultimately have the effect of reducing the number of miles driven within the city and probably reducing the amount of driving to the city, since an auto would be a liability downtown. Whether such initiatives would stimulate traffic elsewhere is uncertain, but reduction of miles in the congested city heart would reduce pollution and the most energy-intensive use of automobiles considerably.

Clearly the key to implementating such a structural solution to energy/environmental transportation problems lies with long range land-use planning. Locating places of work near housing and recreation, spreading commerce along several built-up but dispersed clusters around the city center, using telecommunications for direct contact wherever possible would reduce the need to move around. While it is difficult to speculate whether such land-use patterns could be brought about, it is important to appreciate the great energy and environmental consequences they would have.

The message from this survey of a handful of conservation strategies, is clear. Improvements in energy use cause significant reductions in energy flows, particularly in built-up areas that are already very polluted. Technical solutions to energy conservation tend to pay back quickly in monetary terms even before environmental benefits are concerned. Herein lies a "free source" of pollution control. Structural or lifestyle changes are hard to quantify on a simple cost-benefit basis and the inferred (or asserted) value to society of improving many environmentally important conditions such as pollution and congestion, may prove more important than energy savings in justifying policy measures.

In the case of the technological consideration, if we priced environmental concerns into energy costs, especially where those costs had not yet been internalized through the costs of traditional pollution control, then energy users would have additional incentives to move towards even lower energy intensities. Suppose that the burning of fuel oil in Washington, D.C. is assessed to have a social cost of $1/barrel in both winter (for space heat) and summer (for peak electric power for air conditioning). If a tax were levied on oil, home owners would be economically justified in adding slightly more insulation to homes, improving the energy effectiveness of air conditioners, and perhaps employing even more heat recovery equipment in large buildings. This would tend to decrease energy use even further. (Quantitatively, if $15/bbl fuel oil is assessed a $1/bbl tax and the elasticity of use, in the long run, is 0.5, not unreasonable for space heating, use might be reduced by 3% in the long run compared with the case of no tax. This exercise is only illustrative, not exact).

Of course a measure that decreases energy throughput by 50% decreases combustion-related pollution by a similar amount, while direct abatement measures typically remove 90-99.9% of pollutants. Clearly, conservation should be viewed as a complement to direct attack on the problem. That conservation saves total resources anyway makes the cost of added control negative, i.e., a direct benefit.

IV. CONSERVATION--SOME UNCERTAIN AREAS

While much of the conservation described in national reports or specialized studies can be labelled "technology," the examples raised in the discussion of transportation point to areas where economic values beyond the energy marketplace will play a role. Moreover, there are some areas where technologies are available but institutional or social barriers exist to hinder change.

1. Small Cars

One area is that of small cars. At present it is difficult to decide whether small cars have a significant safety penalty vis a vis large; to be sure, large cars offer much more cushioning (through energy-absorbing material) than small, in a crash at a given speed. And European political traditions appear to forbid moderation of speeds, which are limited in Sweden and in North America among the major auto-intensive countries (110 km/hr maximum). This frustrates concerns with auto safety regardless of the size of the auto. On the other hand small cars can be maneuvered more easily than large, perhaps cancelling the advantage of the "armour" of gas-guzzlers. This issue, however difficult to resolve, is important, especially in the transition period to smaller cars in North America, when 3-ton autos still abound and "threaten" one-ton, energy-saving ones. Drivers' concerns about safety are important, so it is clear that the safety aspects of smaller cars must be studied further.

2. Indoor Air

Another area of uncertainty is indoor air quality, referred to above. At present much research is taking place, especially in Sweden, Denmark, and the U. S. A., where thermal integrity of new structures will be the highest. While heat exchangers will probably solve the air pollution problem, more research is needed into problems that arise with dampness in walls that accumulates when the flow of air is cut back purposely (see Box 5).

3. Mass Transit

Mass transit is an area where energy savings are often cited. Indeed most national governments emphasize the role of mass transportation--as a technology--in energy savings campaigns. But the evidence from America and Europe over the past three decades argues that the role of mass transit as a technology will be minor indeed in future transportation plans unless the role of other institutional factors related to the use of the automobile is recognized.

For example the share of mass transit miles in total passenger miles has fallen all over Europe and America during the past decades. While the absolute number of transit passenger miles has moved upwards in some countries (and downwards in others), the number of auto miles has increased dramatically and nearly in proportion to auto ownership. Rising incomes, land use and tax policies that encourage single family dwellings, and pollution in cities have all encouraged spread and sprawl of the population, and the auto has made the resulting patterns liveable. That is, ownership of an auto allows shopping at dispersed centers, rather than around the corner, allows members of a household to work in different parts of a region and yet live within the same distance (as measured by commuting time) as those people still living in the densest areas and riding the bus.* If the frequency of trips is increased radically, or the number of routes is increased to limit stopping times, then costs go up, especially energy costs. That is, unless doubling the number of seats doubles ridership, the service will be more energy costly.

The difficulty with our example is that mass transit does far more than conserve energy. Indeed evidence exists that expensive fixed rail systems, such as San Francisco's BART or Washington DC's METRO, save little if any energy because of enormous energy investments in guideways, and low load factors. Moreover BART encourages families to live <u>farther</u> from work.

If mass transit on the other hand were considered as an environmental measure--relieving congestion, removing combustion-related pollution to electric power plants (in the case of electric transit), lowering traffic fatalities, increasing free space downtown by decreasing the need for parking--then the case for strong measures to encourage mass transit use would be far stronger. Some possible measures were discussed above, but we can add here

- special off peak rates to encourage off peak use (Gothenburg, Sweden offers free return trips for the price of one-way during midday),
- free downtown circulating shuttles to eliminate short auto trips,

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*A recent Swedish study shows surprising results in this regard. The number of jobs within 30 min of a given area was 3-5 times greater when auto transport was considered than when mass transport was considered. The results were valid for Stockholm, both for the densest downtown regions and the outlying region.

- clustered moderate-to-high-density dwellings around mass transit stations,
- allowing tax deductions only for commuting using mass transit.

Of course variants of these proposals have been in force in some OECD countries for many years, and have certainly helped mass transit maintain its standing. If mass transit is to significantly increase its share of traffic and cut deeply into fast-growing patterns of auto congestion, strong measures will have to be taken soon to discourage auto use, both in cities and between cities. At present the onward march of autoroutes (or autobahn) in central Europe and high speed limits assure that the auto will continue its supremacy, at considerable energy and environmental cost.

4. District Heat

A similar situation exists under the rubric of district heating. By district heating (DH) we mean provision of space heat and domestic hot water by means of large heat centrals where heat, possibly cogenerated with electricity, is produced. While Sweden and Denmark have the greatest coverage of space heating needs with DH among the OECD, serious studies for Germany and the U. S. A. have suggested that more than half of existing heat needs there could be met by DH.

The most important advantages of DH may be environmental. Often-cited Swedish studies show significant decreases in SO_2 levels in cities when individual boilers are replaced by large centrals, burning less expensive heavy oils under far more expert supervision. Losses in distribution are about cancelled by the significant increase in heat transfer from fuel to heat medium (hot water) compared with individual buildings' boilers. Cogeneration increases the energy savings even more.

The problem with DH is its economics. Certainly DH systems pay off handsomely in truly cold climates, such as in Sweden. In Central Europe, however, more than two to three times as much energy per degree day is consumed as in Sweden, according to an OECD study carried out by Lindskoug. Yet it is commonly asserted that lowering the intensity of heating by insulation and weatherization in Central Europe is far more expensive, per GJ saved, than district heating. This assertion is extremely questionable. In Sweden, Denmark, and the U. S. A., where heating data has become extensive, estimates of the savings possible through improved thermal integrity of existing structures have been surprising. Moreover systems relying on electric or gas heat pumps and/or solar heat also compete with DH and may prove to be less costly in the long run.

Reducing the heat demand/km^2 increases unit costs of DH, which are dominated by investment in generation and transmission. Moreover present consumption in Sweden, and presumably Denmark, is bloated by the lack of individual meters in homes, such that 20-40% more heat is consumed than would have been the case had marginal use been metered. Put another way, the consumption of heat in residences in Sweden, per capita or per sq-meter, is nearly as great in multiple family dwellings (MFD) as in single family dwellings (SFD). Engineering tells us that the MFD should have significantly lower intensities. But it is well known that as Swedish apartments become metered consumption will fall but unit costs will rise somewhat. As investments are made in higher integrity, consumption falls farther and unit costs rise even more. Indeed some in Sweden are concerned that new standards on thermal integrity make electric resistance heating (possibly with nighttime accumulation) the least expensive form of heat after direct oil firing--DH cannot complete with achievable lower heat demands.

Moreover, the distribution losses from DH, being fixed, begin to show up in the cost. In the case of single family dwellings or low density multiple family dwellings, the economics of DH deteriorate even further.

These pessimistic arguments about DH in countries with moderate climates should not be interpreted as a judgment against DH. DH still offers energy savings, even though increased weatherization of structures reduces those savings somewhat relative to individual firing. But DH still allows great increase in the control of pollution, from a given fuel, and fuels besides low-sulfur oil can be burned in large, expertly manned centrals. These fuels--wood, coal, high-sulfur oil, biomass, even nuclear fuel--may not be less expensive to use than oil, but they offer relief from low-sulfur oil or gas imports. This flexibility may be of great value to governments looking for alternatives to imported low sulfur oil. As discussed at the outset, however, that goal is different than the desire to economically conserve energy.

Unfortunately, one great fear remains: Suppose we replace relatively clean oil or natural gas in individual boilers with coal or other biomass. There is a great danger than the resulting system, while using somewhat less energy, will produce considerably ore pollution even after measures have been taken, particularly if the expense of pollution control is seen as a threat to the DH economics. Would it not be better to reduce oil and gas use by earnest weatherization rather than by replacement with DH? Professor Hoeglund and his group in Sweden found that the cost of reducing heat losses in an apartment building in Stockholm that lay closer to central European heating intensity was surprisingly low. Given that environmental benefits occur, both to this scheme and to DH, society would be interested in either beyond the level of investment dictated by market prices. But weatherization can occur on a home by-home basis without any need for a district wide plan. Cities with moderate climates ought to follow the advice given in "Energi Hushaallning i Befintliga Bebyggelse" (Energy Conservation in Existing Buildings, State Planning Board, Stockholm) and thoroughly investigate the possibilities for improving existing buildings and their heating systems before embarking upon a large-scale district heating scheme.

The view of district heating taken herein is somewhat unconventional--while engineers in many OECD countries are carefully planning the shapes of attractive DH system, few if any have asked whether the resources required for DH could be more efficiently applied to other forms of energy conservation. Certainly the evaluation of the attractiveness of DH must take into account many costs and benefits that fall outside of the normal market place, especially comparison of the institutional difficulties of lowering heat demand through retrofits vs district heating. Like mass transit, however, DH can be considered in a much wider framework than simply as an energy conservation measure. If this is done DH may become even more attractive as an energy measure.

Recycling

Recycling is an area which has always promised energy and environmental savings. As Table 5 shows, the energy required to recycle most materials is a small fraction of that required to process virgin ore. Materials used in packaging present particularly attractive options, since their lifetime as emballage is short and they often end up as litter. The litter aspect has promoted many jurisdictions in the United States to pass laws banning non-returnable beverage containers or requiring container deposits. In almost every case the once important contribution of containers to road and countryside litter has decreased markedly.

But recycling faces a host of difficulties, as Page (1977) and others have pointed out. For one thing producers of virgin materials often enjoy tax advantages not accruing to "re"-producers. If environmental costs of producing materials are not internalized then the cost distortion is even greater. Finally shipping rates for virgin materials are different, and usually lower than for used materials, at least in the United States.

Technically, recycling faces problems beyond the gradual decay in recycled material purity. For example, few products are made today to be easily dissembled. Additionally, few jurisdictions require separation of trash by consumers before collection. Finally, some products, such as paper and other organics or motor oil have a heating value that in some cases might exceed their scrap value, just as wood "wastes" from pulping may be more valuable as low-grade sources of cellulose than as fuel. Here relative prices and technologies are decisive.

There is, however, a societal aspect to recycling not always considered. If products were made more durable, there would be less to throw out; if products were made more optimally with respect to materials which is occurring now as raw materials rise in price--there would be less material in a given final product; if packaging was made more carefully (or even charged for in stores), there would be less material flow in society. Many of these changes are taking place in response to ordinary market forces.

Thus an auto lasts longer in Sweden than in the U. S. not only because some autos made in Sweden might be more durably made than in the U. S., but because the high taxes on autos in Sweden raise the price of a new car relative to a used one and relative to the cost of repair and maintenance. This in turn may stimulate Volvo and Saab to produce more durable cars than their American counterparts in similar price ranges. Since a ton of car requires roughly a ton of coal, the energy savings* and the environmental pollution saved are considerable (see Berry and Fels, "The Production and Consumption of Automobiles").

But if material flows in society are smaller <u>than otherwise</u>, economies of scale important to collection and processing may disappear. On the other hand most materials <u>cost</u> to dispose of; this cost, usually subsidized today, should be credited to the process that reuses them.

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*About 1 year's worth of gasoline for normal driving.

Finally, a good deal of steel and aluminum is already recycled, particularly the steel hulks of autos, ships, and equipment. And a new industry, the "rebuilding" industry has arisen. In the U. S. one can purchase a rebuilt engine for a car or a rebuilt appliance for less than a new version. Obviously the economic incentive to produce such goods exists in some places, but many consumers are not yet used to the idea that "rebuilt" may be better than new.

Yet as these recycling changes begin to occur more widely, the energy and environmental benefits will be unmistakable: avoidance of mining and benefaction with their attendant air and water pollution and land use; avoidance of large inputs of process heat; probable reductions in the distances involved in shipping material and a possibly profitable shift from employment in capital- and pollution-intensive extractive and energy-harvesting industries to less capital-intensive assembly industries. Some studies have already estimated the overall impacts of a shift in materials use, such as Hannon's classic evaluation of the beverage container industry in the U. S. While institutional changes are required that often delay new patterns for decades, rising energy and materials prices will favor re-use and recycling more and more as the most efficient use of all resources. Thus we should expect greater interest in this subject and subsequently energy and environmental benefits, especially as environmental costs of producing energy and virgin materials are internalized into our economic system.

6. Lifestyles and Structural Change

Ultimately structural changes must be considered in the economic-environmental-energy planning process. This is because sudden disruptions in energy supplies will expose the vulnerability of a society too dependent upon inefficient heating systems in dispersed suburbs, large amounts of travel per capita, and heavy reliance upon the automobile. This is not to say that such energy-related systems are bad, only that they are particularly sensitive to changes in energy prices and availability. While OECD countries consider policies that will stimulate reductions in energy intensity of autos and homes, they may also wish to confront the issues of reducing urban sprawl and miles driven--the "Americanization" of transportation that is already taking place in Sweden. For it is not clear whether the classical nature of the design of European inner cities can withstand the increased onslaught of auto commuting and inner city auto use that has characterized America for nearly three decades, given the expected increases in energy prices and environmental stresses that are already mounting.

Similarly, structural change must be confronted in the industrial sector, even as more energy-efficient, less polluting processes take much of the energy-environmental strain out of the economy in the medium term. Stagnation in the production of steel in most OECD countries, and the slowdown in paper and pulp production in Sweden are due in part to increases in the prices for energy. Unless we can effect an extremely rapid transition to very energy-efficient technology--which means scrapping many otherwise profitable (in pre-1973 terms) factories--we must accept slower growth in the most energy- (and pollution-) intensive industries. At this point we must ask to what extent we should pump new life into these branches? Allowing instead more growth in the less energy (and pollution) intensive light manufacturing sectors, as is now expected in Sweden and as has taken place for many years in the U. S. A., will of itself lessen the overall energy and pollution burden of industrialized countries in the long run for a given GDP. Of course we are not completely free to adjust the inputs and outputs of modern industry. Nevertheless, the prospects and problems of structural and lifestyle changes that either reinforce or go against today's trends must be confronted today, lest we lose some of the flexibility of the energy system in the long run.

What will be most difficult for governments is to decide when to operate with policies that go beyond the marketplace in effecting structural change. Gasoline taxes, for example, act to keep the size of autos small, but seem to be ineffective in halting the growth in the number of cars. This is understandable, given the convenience of autos. Allowing tax deductions for dispersed single family dwellings or commuting (mentioned above) worsens the energy-environmental problem. While the goals of living far from work and owning a single family dwelling may be laudable in and of themselves, these goals must be reconciled with energy and environmental policy. Should governments be subsidizing structural increases in energy use (more miles, detached homes) at the same time as they subsidize technological decreases in energy intensity? The answer is not clear, but the question will become increasingly important as auto ownership outside of North America, and auto use everywhere increases.

Structural change has an important effect upon energy and environmental demands. Unfortunately, most energy forecasts--and policies--have the structural trends of the 60's and early 70's built into them--more miles in larger cars going to and from larger homes. Recognition of this element of energy planning is important. Similarly, most energy plans attempt to meet industrial demands based upon continued and rapid growth of energy intensive chemicals, metals, and paper industries. Experience in one country, Sweden, suggests that a more sober evaluation of future growth prospects shows growth indeed, but at far lower rates than usually assumed. While this is bad news for those industries caught unprepared, it is good news for energy planners--there is less demand pressure, and it is probably acceptable in the long run both economically and politically, provided that Sweden is prepared for the accompanying changes in the growth patterns of energy-intensive industries.

V. THE ENERGY COST OF POLLUTION CONTROL

Thus far we have familiarized ourselves with several important aspects of the energy-economic environment circle. We found that energy conservation, motivated largely by economic forces, required the most productive use of all resources, including energy. We found that most conservation strategies reduce combustion-related pollution considerably and pollution from material flows as well. We noted that there were several energy-related systems that reduced energy use and environmental problems, systems in which energy considerations might not be as important as other aspects. Either way, strategies that result in energy conservation are generally beneficial to the environment even before any outlays are made for traditional forms of pollution control. Conservation is the least expensive form of "clean."

When we confront pollution directly, however, we find ourselves facing expenditures for energy to run pollution control systems. These energy costs are well known and are summarized for a variety of classes of activities in Table 6.

Environmental expenditures fall into several generic areas:

- energy expended to clean up fuels before combustion
- energy expended to clean up exhaust from combustion
- energy expended to convert primary energy to more environmentally acceptable forms of secondary energy
- energy expended to run abatement devices in non-energy industries
- energy expended to run waste treatment systems
- energy expended to improve the work environment (Box 4, above).

What bothers some observers is that these energy uses are "new" in the sense that societies did little to combat pollution a few decaded ago. Seen historically, the use of energy for environmental controls increases energy use at least somewhat compared to the situation of less control or no abatement at all. Do these increases in energy use somehow constitute a conflict with policies and goals designed to conserve energy, as Helmersson and others sometimes state or imply?

To answer this question, we first recall our discussion of conservation and other political or economic goals. While lowering oil imports is a political goal to many governments, it is not necessarily an economic goal to individuals or society unless it results in a more economic use of all resources. Such is the case, we argued, for most of the important energy conservation strategies. But the goal of conservation is not "less energy" per se, particularly because energy use totals or energy intensities do not in themselves measure economic efficiencies or social well-being.

Thus uneasiness about energy expenditures to meet environmental needs is at least in theory not well founded. So what if energy is expended, if an important economic and social goal, lower pollution, is achieved? Of course some may disagree about the economic value at the margin of a reduction in pollution. Here we side clearly with those who place a rather high value on environmental clean-up strategies.

For it is becoming clear to many observers (see Ehrlich, Ehrlich and Holdren) that parts of the world lie near the threshold beyond which further environmental insults from production activities may cost more than they allow in direct economic benefits. Crowded industrial areas like the Ruhr District in Germany, parts of the U. S. North Central and North East, areas around Tokyo, and valleys in Sweden with intensive paper production activities, are some areas that immediately come to mind. In every case these regions are at least particularly "redeemed" by intensive application of environmental control technology at measurable energy cost. And most of Europe will soon follow the lead of the U. S. in developing anti-pollution standards for automobiles, as smog becomes more prevalent in the capitals of Europe. Put simply, new or existing economic activities might become politically or socially unacceptable in crowded regions without the existance of pollution-cutting measures.

This is particularly true of energy. High-sulfur fuels have become unburnable in many crowded areas. Expending energy to clean these fuels "unlocks" them for use, albeit at a cost in the decay of air quality.

In the more extreme case where coal is converted to liquids or gas, the loss in gross BTU theoretically available in the original form of coal is counted as the loss in energy due to environmental controls. Yet this loss is really society's gain, since the liquids or gas that can be produced have greater economic value than the coal consumed, and the clean fuels are far more benign environmentally than raw coal. Again confusion arises because we ascribe some magical value to a joule itself, rather than to the value of that joule when used in various processes to produce goods and services.

The most perverse case is that of solar energy. Uninformed critics often cite the low energy conversion efficiency of various solar devices, forgetting that solar devices essentially convert capital, not fuels, into useful energy. Again accounting using the joule alone is a woefully inadequate way of measuring the effectiveness or correctness of a particular energy conversion strategy, especially when clean environmental benefits result.

When the energy costs of pollution control are examined more carefully, however, the situation becomes less disconcerting. For one thing, these energy expenditures are accompanied by expenditures of other resources (Box 2, above). Whether the new process (i.e., the "clean" process), is <u>significantly</u> more energy intensive than the uncontrolled version, measured in GJ/$ output, is not clear. The energy impact of a particular environmental expenditure must be compared with the uncontrolled case where estimation is made both of how much of the good produced would have been consumed, presumably costing less without pollution controls, and how the money not spent for pollution control would have been spent. Essentially, expenditures for pollution control are paid for in the short run by decreased expenditures for other goods and services, including costs of pollution control. They typically range from 0 to 8% of the energy expended otherwise in the process, as the figures in Table 6 show. We have already seen that technical advances tend to decrease these energy penalties, as environmental goals are built into new technologies rather than added on afterwards.

The automobile is a good example. Many studies show how the early types of exhaust emission controls in the U. S. increased fuel consumption, often dramatically. This, and additons to safety equipment that resulted in weight increases, were often "blamed" for high energy consumption in American cars, though the data clearly reveal the underlying size and weight of American vehicles as the main cause of higher energy intensity than autos in Europe.

Figure 3 shows clearly that the exhaust emission energy penalty applied mainly to larger autos. Smaller cars produced fewer pollutants to begin with, since fuel consumption per mile was half or less of that of larger cars, and smaller cars have larger weight-to-horsepower ratios, and therefore run at a larger fraction of their optimal running speed than larger cars. The latter were over-dimensioned for acceleration capability, which depended upon weight and driving conditions.

But in the intervening years since 1973, energy requirements for auto emission control have decreased dramatically as engineers have rethought the problem of clean engines. Various types of fuel injection, systems, stratified charge engines, diesel engines and changes in fuels have lowered these energy requirements. The options are well summarized in Ross et al. (1975).

The lesson here is that while initial counterattacks on pollution may be expensive in energy and other resources, technologies tend to be developed that reduce the cost of cleaning up. Thus near-term technologies may give bloated estimates of the energy requirements of pollution control even as controls are tightened in the future.

Moreover it is doubtful that the historical growth rates in energy production (or use) and production of energy-intensive raw materials or finished goods will continue into the future in the wealthiest countries. Laying aside the issue of material growth itself, it is clear that higher resource and energy costs as well as the cost of internalized pollution controls push up the cost of these goods relative to less pollution intensive goods and services, which increase market share. Such a "transition" has been occurring in the U. S. That in turn means less pressure to advance environmental standards in a region to keep environmental quality level.

Moreover, many basic energy and material processing industries are relocating in developing countries, for better or for worse.* This is especially true of the most energy-intensive industries, which tend to find their way to regions of cheap energy. The concentration of aluminum producers on the Columbia River in the U. S., once a source of extremely low-cost hydroelectricity, will probably be reduced in the coming decade as the utility there turns increasingly to high cost thermal generation. Since there is neither aluminum ore nor a great aluminum market in the Northwest, the role of cheap energy in attracting the aluminum industry is undeniable. Most of the OECD countries face difficult decisions about the future of energy intensive industries now burdened with far higher energy costs than ever imagined. Industries that cannot conserve (and probably reduce pollution as well thereby) will find themselves unable to compete with more efficient industries or those located closest to sources of cheap inputs.

The result, in the long run, should be a shift from basic materials to high value added, knowledge-intensive manufacturing, already noticeable for the United States vis a vis Europe and California compared to

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*One reason might be the lack of environmental standards, another low-cost ore and labor.

the rest of the U. S. (see T. Bradshaw's important analysis). This presupposes that the materials and energy that are required are available in other parts of the world, which appears to be the case. But industries in materials-and energy-producing areas will be new and likely based on the most advanced and productive technologies, as in the case of German and Japanese steel production compared with American. Unless governments in these new producing regions take a particularly laissez faire attitude towards pollution control, the overall outcome will be replacement of outdated materials processing facilities in the industrialized countries with modern facilities in developing countries and high value-added industries in both regions.

This future, while somewhat speculative, is understandable in terms of trends in resource costs and product costs. The overall gains in energy and environmental economies should be significant.* Thus from a structural point of view the future of the energy-economy-environmental interaction is rather bright.

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*Recall that even in the post World War II era falling energy costs were accompanied by significant gains in energy efficiencies because newer technologies almost always use less energy per unit of output than old. Even if areas rich in energy at lower costs than Europe, North America and Japan these areas can use new energy efficient technologies profitably,[8] not being saddled with factories that date back three-quarters of a century.

VI. SUMMARY AND CONCLUSIONS

This review has focused on key aspects of the energy-environment economy interaction.

- Energy conservation almost always reduces pollution problems considerably, at a net economic savings rather than a cost.
- Most pollution abatement strategies and technologies require some energy and other resources. In time the energy costs of these strategies tend to fall. In any case total energy expenditures for a nation's environmental controls are relatively small, typically less than 5% of a nations total energy consumption (Table 7).
- A few energy conservation strategies have environmentally-related hidden costs that must be watched carefully.
- Some popular energy conservation strategies, like mass transit or district heating are best considered as environmental strategies, for which energy conservation is a hidden benefit. Land Use Planning might reduce energy use and pollution but appears to depend on social factors beyond the energy-environment debate itself. Nevertheless, environmental consideration alone may force governments to take strong actions beyond the marketplace to limit the use of automobiles.

The results of this discussion should be clear by now: There is no real conflict between energy conservation goals and environmental goals. Energy is required in moderate amounts for environmental measures, but energy is required for all human activity, and pollution control, while in some cases itself a somewhat more energy-intensive activity, is no special case here. The notion of a conflict between kinds of goals arises out of a misunderstanding over how to measure energy use and progress towards energy conservation goals. Since the expenditure of energy itself is neither wasteful nor efficient per se, we should view the small energy price of pollution control as a necessary expense to achieve an important result.

It should be noted, too, that the figures typically cited by our sources as representative of the increase in a nation's energy budget due to pollution control, 2-4% of total national consumption lie within one year's growth of energy (at pre 1973 rates) in nearly every OECD Country (Table 7). But data from most OECD nations indicate that since 1973 key energy intensities have been reduced enough to have effected savings in energy use greater than total energy expenditures for environmental purposes in future years. Yet the conservation recorded thus far is short term and relatively minor compared to what is expected as new factories, buildings, and vehicles have replaced today's stock. Thus we have already "paid" for environmental control with a relatively modest effort at energy conservation.

Clearly much remains to be accomplished. Rising prices for all forms of energy, in spite of today's constant world oil price, will ultimately push modern societies towards full adoption of energy-conserving technologies through careful investment. At the same time improvements in technology will lower the energy and economic cost of a given level of pollution abatement. This is particularly important since increased levels of overall economic output will otherwise require increasing expenditures for environmental cleanup per unit of output. Each technology reaches harder and harder to remove small amounts of residuals while economic growth increases the total flow of materials and thus pollution. Thus it will be important to anticipate new technologies that will increase abatement for a given cost, as well as structural changes in advanced economies that will reduce the environmental strains of a marginal unit of economic growth. As Singer suggested in 1975, however, the total dollar and energy cost of environmental cleanup will never become a dominating cost.

However, there are many unknown areas ripe for research today that could yield substantial benefits to policy makers in search of intelligent choices. The conservation strategies we referred to as "troubling" deserve much more attention. To what extent can societies meaningfully implement land use planning? The social costs and benefits of district heating deserve much more careful scrutiny that they have received. The problem of indoor air quality, now receiving technical attention, should also be seen as a case study of society's timely response to a potential conflict between energy and environment. Hopefully similar work in the area of auto safety, speed, fuel consumption, and size will appear soon.

Last, but not least, we need to know more about pollution control technologies for planning purposes. What are the ultimate limits on energy consumption for pollution control? How will "Non-Waste Technologies" combat both pollution and conservation problems simultaneously? What systems-solutions for both problems might appear in the near future? Will firms with limited capital follow government guidelines on conservation or pollution control first? Will higher energy prices cause some scrapping of older, more polluting factories in favor of new, cleaner energy-efficient factories? Will pollution and energy costs cause structural shifts in economies or major relocations of industries? These questions are being asked today by individual firms, but they should be considered holistically by energy and environmental specialists at all governmental levels.

VII. POLICY IMPLICATIONS: FINAL THOUGHTS

The historical predeliction of industrialized governments to seek new sources of energy supplies is understandable, in view of the fall in energy prices during the decades following World War II. While the importance of clean, new, energy supplies, domestic or imported, cannot be overemphasized, the search for new energy must be met with an equally vigorous search for new energy saving technologies and new patterns of living and production that may reduce energy needs further. The impetus for the former conservation goal is primarily economic--saving energy will mean saving money--so governments should begin to price energy at its marginal, social cost. The reason for the latter goal is both energy and environmentally based--industrialized societies can ill afford further over-dependence on cheap energy and the free services of the environment, when these two low-cost resources are quickly disappearing.

Most important, however, is the reminder that the overriding determinant of the environmental burden caused by energy production and use will always be the total level of energy use. Put simply, the more we use, the more each unit will cost us in direct and indirect costs, particularly environmental costs. Worse, each of the substitutes for imported oil and gas has characteristic environmental problems that, while difficult to quantify (the risks of nuclear power) or tempting to ignore (the risks of increased coal or biomass use) must be included in policy decisions that attempt to steer countries away from oil and gas.

Conserving oil and gas by improving end-use utilization appears to present far fewer external problems of an environmental or social nature in the long run, because improved end-use utilization is by nature technological. Whether structural and lifestyle changes--or rather changes in the direction that lifestyle and economic structure might otherwise evolve--are easier or more difficult to accomplish than changes in energy supplies--is uncertain, as the debate over the ideas of Amory Lovins (U. S. Senate Small Business Subcommittee, 1977, 1978) has made clear. Nevertheless it is important that energy and environmental policy-making pay more attention to avoiding environmental stress from the beginning, through careful applications of conservation technologies that reduce the growth in energy use, rather than simply rushing onward the development of high-cost energy supply and the adding on of expensive pollution control equipment that will itself demand a small price in energy use.

To the extent that certain conservation strategies, whether technical fixes (tightening of buildings) or structural-lifestyle changes (less auto use, district heating) may themselves encounter technical, environmental, or political difficulties, these problems should be anticipated and dealt with in advance. Difficulties with indoor air may force us to forego a small part of the savings in energy that increased thermal integrity would make available. Inflexibility of people's habits or housing patterns may slow the spread of mass transit or district heating. Demands for clean industries, both indoors and outdoors, will exact at least some price in terms of energy use. These energy costs are affordable and should be accepted, rather than used as a distraction from the meeting the complementary challenges of energy conservation and a clean environment.

Finally, we have continually stated that market forces, particularly the prices paid for energy forms, are important in the decisions made regarding conservation technologies. Since many energy related goals transcend market place values, however, governments must be ready to evaluate and justify those goals. The most important of these goals is of course the desire to reduce the import of fuels and move away from oil and gas <u>more quickly</u> than the marketplace alone would dictate. To the extent that social and political goals are included in energy decision making, the importance of conservation and environmental values must be given equal weight with the more popularly expressed goals of reduced dependence upon oil and gas. Ultimately it is energy conservation that offers the greatest possibilities for satisfying the diverse goals of energy, environment, and economic well being.

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TABLES

TABLE 1

Some Energy Forecasts

Region	Year	Range of Demand, EJ	Range of Per Capita Demand, GJ	Source, Notes
USA	2010	62-150	225-540	CONAES, *Science* 200, 14 Apr 78
	2025	≲60	≲200	Lovins, *Soft Energy Paths*, Ballinger Books, 1977
Holland+	2000	A factor of 2.5	---	*Second Interim Report*, Dutch National Energy Research Steering Group, 1976
New Zealand	2025	.5-2.5	150-500	*Energy Scenarios for New Zealand*, New Zealand Energy R&D Committee, 1977
Switzerland+	2000	.9-1.5	~ 180-300	*Stabilisierungs Varianten*, report to the Swiss Fed. Comm. for Energy Policy, Bern, 1977
Sweden§	1990	1.7-1.95	200-230	Industriverket - March 1977
	1990	1.7-1.95	200-230	Energi Kommissionen
	1990	1.4	160	"Malte," Energi Kom.
				All from Industridept., Stockholm
Denmark+	2005	1.4-2.1	250-380	Danmarks Energi-*forbrug i Samfund-soekonomisk Belysning*, part of IFIAS study on Danish Energy Future, Danmarks Kedelforeningen
WAES	2000	365-455	+	World outside communist areas

§Not all losses included in Swedish accounts

+For estimating per capita use population estimated from other sources or unavailable.

TABLE 1 (continued)

Shown are a variety of energy forecasts and scenarios. The differences in per capita consumption arise out of differing assumptions about economic growth, lifestyles and policies. Much of the difference within each country, however, depends on the evolution of energy prices and the conservation response. It is clear that the environmental consequences of the higher energy scenarios, by country or globally (WAES), are considerably greater than in the lower, and that some countries may be forced to apply more pollution abatement technology at greater energy cost in the high scenarios compared to the low. Note that solar contributions to space heating are probably not counted.

Table 2. Comparison of rapson effluent-free process with standard Kraft slush pulp (new mill basis).

Item	Process	Standard Kraft
Plant Investment, Pollution Control ($ million)	140	154
Operating Cost ($/ADT) Incl. Pollution Control	259	290
Purchased Energy (10^6 BTU/ADT)	2.1	7.4
Pollution Loads		
Water Volume (10^3 gal/ton)	20*	31
BOD (lb/ton)	none	66
TSS (lb/ton)	none	66
Color (lb/ton)	none	300
Air Emissions		
Particulates (lb/ton)	200	200
TRS (lb/ton)	24	24

ADT = Average Daily Ton capacity.

*Aqueous effluent is "clean water" only. Source T.V. Long, "Non Waste Technologies," Univ. of Chicago, 1978. Taken from Report No. EPA-600/7-76-034e, A. D. Little Co., December 1976.

Table 3. Passenger transportation: 1972.

	Pass-MI/cap	MI/auto	% Auto	Energy/Cap (MWh)	Intensity	Gas price (US=100)	% of income	Auto ownership, cars per 1000 people 1961	1972
United States	11,300	9,360	92	9.4	.90	100	3.4	344	462
Sweden	6,280	8,900	84	(3.8)	(.60)	(180)	(0.8)	173	303
Canada	6,550	10,000	88	6.3	1.1	(110)	____	237	377
France	3,980	____	77	2.2	.71	256	0.7	133	269
W. Germany	5,870	8,900	82	2.4	.51	243	1.1	92	253
Italy	4,160	7,610	80	2.2	.65	348	0.6	48	229
Netherlands	4,620	10,000	81	2.2	.59	____	____	53	229
United Kingdom	4,990	8,950	80	2.0	.49	192	1.1	113	230
Japan	3,760	____	34	0.9	.74	250	0.2	7	119
Europe avg.	4,840		80	2.3	.60	____	____		

Source: RFF; IEA; Swedish data modified by Schipper and Lichtenberg; Prices for gasoline, income shares from RFF; distance/auto/yr from WAES.

<u>Passenger transportation</u>: Shown are the total miles, the share taken by autos, the resulting per capita energy consumption, the intensity in kwh/passenger mile, the gasoline price relative to the US, and the percentage of income spent on driving. Finally, auto ownership figures for 1961 and 1972 are shown, displaying the rapid growth in Europe and Japan that still lies far from saturation.

Table 4. Indoor air pollution in residential buildings.

SOURCES	POLLUTANT TYPES
<u>Outdoor</u>	
Ambient Air	SO_2, NO, NO_2, O_3, Hydrocarbons, CO, Particulates
Motor Vehicles	CO, Pb
<u>Indoor</u>	
Building Construction Materials	
Concrete, stone	Radon
Wallboard	Formaldehyde
Paint	Mercury
Installation	Formaldehyde, Sulfates
Building Contents	
Heating and cooling combustion combustion appliances	CO, SO_2, NO, NO_2, Particulates
Furnishings	Organics, Odors
Natural gas; water service	Radon
Human Occupants	
Metabolic activity	CO_2, NH_3, Odors
Human Activities	
Cigarette smoke	CO, NO_2, HCN, Organics, Odors
Aerosol spray devices	Fluorocarbons, Vinyl Chloride
Cleaning and cooking products	Hydrocarbons, Odors, NH_3
Hobbies and crafts	Organics

Table 5. Recycling energy use as a fraction of energy cost of virgin materials. Collected by Steen and Wiman (SW).

Material	%	Source
Magnesium	98	SW
Aluminum	96	SW
Titanium	69	SW
Steel	52	SW
Iron	55	SW
Copper	88	SW
Zinc	88	SW
Lead	87	SW
Plastic	96*	SW
Cardboard	50*	SW
Paper	50*	SW
Glass	0-15	SW
Containers: Reusable Bottles vs Throwaway	66%	Hannon

*Has alternate value as fuel.

TABLE 6

Energy and Pollution Controls

Activity		Abatement-Reduction	Energy Penalty	Source
1. FUELS				
Low-Sulfur Oil, Refined		90%	3-6%	1
Coal Benefaction-US Coals:	S	13-35%	2.5-23%	5
	Ash	5-55%	2.5-23%	5
	Gasification	99%	40-60%	-
FGD (scrubbers)		80% SO_2 99% particulates	4-7% up to 10%	1
Electrostatic precipitator, Electric power plants		90-99% particulates	.1% of final consumption	1
Dry Cooling Towers		Virtually no cooling water	3% of fuel consumption	1
2. USE				
Auto Emissions (CO, NO_x, HC)	USA	80-90%	(-3%)-(+3%) but 5% on heaviest	1
	ECE	80-95%	4% on heaviest	4
Industrial Air: Combustion, Particulates and H_2O			1.25% of US demand, 1985	1
Heat Dissipation (Dry Towers)			"	
Work Environment			1-4% of Industry	2,3
3. SOLID WASTES				
H_2O			0-(-1.3%) of US (i.e. can be energy source)	1

Sources:
1. Ross, et al.
2. Steen and Wiman
3. Wene
4. OECD, Working Group on Emission Controls
5. OECD, Group on Energy & Environment, ENV/EN/77.9

TABLE 7

Energy, Environment, and National Energy Budgets

1985

Country	Percent of Total Energy Use for Environmental Measures	Notes
USA		
Hirst (ORNL)	3	
NPC	3	Cited in Steen & Wiman
Ross, et al.	3.4	2.1% with Waste Recovery
Holland		
Steen & Wiman	2.4 - 5.2	Cited in Steen & Wiman
Sweden		
Steen & Wiman	1.8 - 2.7	Not including space heating of factories
Norway		
Helmersson	4.6 - 6	

BOXES

FIGURES

BOX 1. ENERGY AND ENVIRONMENTAL ACCOUNTING

In order to compare various activities involving energy expenditures, it is necessary to distinguish between the level of activity, O, measured as an output of tonnes, a distance in miles, or a value in currency (such as dollars) and the energy used in such an activity per unit of output, E, called intensity. The total energy involved in the activity is T = O x E. (If an economy consists of n classes of activities, we subscript each one with a j (j = 1,2...n).)

Suppose we now insist that a certain activity (O_j) be modified to include pollution abatement measures. In general, but not always, these modifications will increase the cost of the activity somewhat (O if output is measured in value), and will possibly increase the energy demanded in that activity (T) somewhat as well.

Not all of the increases in energy demanded appear at the site where the activity is carried out (or product produced). Instead, upstream activities, such as production of pollution control equipment bought by producer "j", embody energy. Ross, et al. show that in nearly every case this embodied equipment energy is small compared to the operating energy of the equipment, which in turn is usually small compared to the energy throughput of the activity j in question.

It is, nevertheless, useful to adopt a formal accounting method for comparing changes in energy flows and intensities. In a given year, the total of all goods and services produced (ΣO_i if O is value added) forms the major part of the GDP. When processes are adapted to pollution control measures, the structure of the GDP (the various O_j) changes slightly, since different goods are required (i.e. pollution control equipment) to produce output J. Moreover, final purchasers must forgo some of O_j (or other O) to pay for pollution control.

What are the energy consequences of the requirement for pollution control? That is, how much energy would the economy require with (and without) the pollution control measure? This is the question of concern.

Let O'_j be the composition of final output with pollution control and O_j without. If a particular good costs less when produced from a polluting factory, then somewhat more of that good is likely to be consumed (how much more depending upon the price elasticity of that good and the substitution possibilities against other similar goods). Conversely, a given expenditure of money for pollution control, if it raises the price for a good, presumes expenditures (or investments) forgone in other activities to pay more for the good in question; and, therefore, less of the (controlled) good is likely to be consumed.

The energy consequences can be accounted for as follows: In the uncontrolled case, total energy consumption is given as

$$T = \Sigma O_i E_i$$

Now add pollution controls: The intensity of a controlled activity E'_i may be different, usually, but not always, somewhat higher. That is, before controls, an amount T_i was expended in energy for producing the i-th activity. After controls, $T_i + \Delta T_i$ was expended, but the cost C_i increased somewhat $(C_i + \Delta C_i)$. Ross, et al. cite cases where the incremental energy expended is less than the incremental cost, on a unit basis, so that the energy intensity of the product from the "clean" technology is actually less than in the uncontrolled case. In most cases, however, the intensity of an activity will increase by a small amount due to pollution control. The overall energy consequences for society will be thus

$$T' - T = \Sigma (O'_i E'_i - O_i E_i)$$

Note that this quantity in general is not as great as simply the sum of all incremental energy expenditures for pollution controls, since the shift in intermediate and final outputs to prepare the controls (and pay for them) means a little less output somewhere else. Moreover, the new economy (O') is, by society's measure, more valuable than before, because pollution is reduced. Unfortunately, as is well known, this reduction is not reflected in the GDP or other common measures of output or welfare.

To describe a concrete example, suppose that 1974 automobiles in the US cost 3 percent more because of pollution control and required on the average 6 percent more fuel compared with the uncontrolled case. More energy (a very small amount) is required to build controlled cars, but slightly fewer will be sold at the higher price. The full cost of driving per mile will be somewhat higher because more gasoline will be used, so somewhat fewer miles will be driven. The net effect on the economy depends on the energy intensities of the activities forgone to pay for cleaner cars and the changes in production and uses of cars (elasticities) arising out of the higher energy prices. The overall effect is to make the net increase in energy use for pollution controls somewhat less than what is obtained when increments for controls are considered alone.

BOX 2. ENERGY CONSERVATION AND THERMODYNAMICS

Are we near nature's limits on minimum energy requirements? Not according to the best estimates of energy use in industrialized countries. The epic APS study in the US compared energy uses for the most important tasks with the minimum amounts of free energy required to perform those tasks; i.e. heat materials and space, move things, transform materials, provide electromotive power for electrolysis or convert fuel into electricity (See Schipper 1976 or Ehrlich, et al. 1977, p. 398-9.). Not surprisingly, they found that the amounts of free energy available in fuels and electricity used by society were in almost every case 3 to 20 times greater than the minima required by thermodynamics. This measure is referred to as "Second Law Efficiency." Ayres and Narkus-Kramer went even further and found that the economy in the US could run on perhaps 5 percent of today's energy if all processes were to proceed reversibly, infinitely slowly (a requirement for minimum free energy use) and if all tasks were themselves to be energy optimized.

However, thermodynamics does not tell us what tasks to do in an economic world, only how we might carry them out. All responsible discussions of Second Law Efficiency recognize this. Moreover, it is recognized that economic and knowledge constraints limit energy use to today's intensities, not thermodynamics. But thermodynamics <u>solely as a guide</u> suggests that we are a long way from nature's limits, so we cannot argue today that we have run out of ways to save energy.

Thermodynamics also places constraints on the minimum energy requirements for pollution control. This is because pollution control, insofar as it involves separating chemical species before they are emitted into the environment, implies an increase in negative entropy of the emissions, requiring the conversion of some free energy into entropy. Ultimately, the total entropy of the system (source plus environment) increases, and the factor contributing to the increase in entropy is the free energy sacrificed to run pollution controls. Of course, the task of pollution control is often redefined -- recirculating water to cut emissions allows the consumption of water in a paper plant (and the loss of valuable chemicals) to be decreased drastically, ultimately reducing the increase in entropy of the total system. Indeed, it is just these types of solutions to energy conservation-environment-economy problems that are represented by the non-waste technologies. Again, thermodynamics is an excellent guide towards methods that conserve energy, reduce pollution and even save money. Ultimately, however, it is usually our private or societal economic valuations of the costs and benefits of the outputs of processes that lead to resource choices, not Second Law Efficiency.

For this reason, comments on the "reduced efficiency" of solar energy conversion processes or electric powerplants with dry cooling towers do not really have economic meaning. Large energy losses incurred in making coal, shale or uranium must also be considered. If engineering or environmental constraints force us to reduce the energy out/energy in ratio of a process (called "First Law Efficiency") or the free energy required/free energy actually used (called Second Law Efficiency), so what, as long as we are better off in societal or economic terms.

BOX 3. ENERGY AND POLLUTION--THE IRON CASTING INDUSTRY IN THE UK

A good example of the energy-pollution interaction is illustrated by a study of the casting industry in England carried out for the UK Department of Energy and Department of Industry in the Energy Audit Series.

In reviewing energy use and conservation possibilities the report noted that the energy cost of implementing existing (1972) regulations would amount to about 2.2% of the energy required to produce one ton of castings. Most of this extra energy was concentrated in a few large foundaries.

The report continues by listing several technologies that would mitigate this energy cost:

- Multicyclone collectors instead of high efficiency wet scrubbers
- Filtration cleaners of electrostatic collectors instead of scrubbers
- Automatic afterburners in exhaust gas cleaners
- Lower volume of exhaust gas

The lesson from this study is that today's environmental energy requirements are small, i.e., a few percent of total energy throughout. In the future, alternative techologies will doubtlessly reduce these costs even further.

The study expressed concern that capital requirements for pollution controls might discourage the investment in energy-saving heat recovery equipment, presumably in existing plant. Of course pollution controls represent society's insistence on internalizing environmental costs, while heat recovery embodies a private firm's desire to save money.

If a firm views its capital situation as difficult it is in effect placing high internal return requirements on investment. The polluting controls being mandatory, the firm may defer (unfortunately) its investment in heat recovery. This problem is, however, not expected to arise in consideration of new equipment, where both energy and environmental conservation measures can be designed into the processes at far less cost than in the case of retrofit.

BOX 4. ENERGY USE AND THE WORK ENVIRONMENT

It has often been pointed out that one emerging environmental requirement centers on the workplace itself. Factory owners realize that a decent work environment increases worker productivity, while workers and medical experts point out that a decent-clean-safe requirement is in the interest of all society, even before overall factory productivity is considered.

Wene considered some of the energy implications of indoor environmental cleanup. There are many types of amenities that workers require: protection from extremely high temperatures found in most basic material processes, protection from outdoor elements (cold and dampness in cold climates), and protection from dangerous emissions within plants (plastics as particles or vapours (witness the PVC and TRIS scandals in the US in 1976 and 1977), particulates, especially asbestos, or process gases such as SO_2).

Both Helmersson and Wene have pointed out that care of the work environment does increase the use of energy per worker, a measure of energy intensity in a plant, though not necessarily a measure of anything else (i.e. energy/worker has no direct connection with productivity). The traditional solution to pollution in indoor air has been to increase the intake of ventilation air into the entire factory by such an enormous amount as to swamp the pollutants and dilute them to acceptable levels. This requires electricity expenditures for large fans as well as reheating of cold outdoor air in colder climates. Of course, the total flood of air eventually reaches the outdoors, so the pollutants leave the factory unabated, especially since their concentration has been so lowered as to make filtering difficult.

Instead, special hoods are now designed to fit over the work. High pressure fans are applied only in the pipes leading from the hoods: the gases leaving the work area in the pipes are of high concentration and filtering can be applied. Moreover, the hot exhaust can be passed through normal heat recovery devices so that not all the heat is lost. Finally, the overall flow of air can be reduced. Wene's typical example, that of a plastics factory, shows that the use of electricity does climb somewhat, but the use of oil for heating does not. Thus, there is an increase in total energy use towards the improved work environment. In a further example, Wene shows how isolation of the work area (where the pollution, in this case, dust, arises) reduces the energy cost of heating and fans. This suggests again that as "systematic solutions" (Wene's words) are employed, the energy cost of a clean indoor work environment can be reduced.

Wene's third example, however, provides the most important insight and best support of our thesis. Wene describes a process patented by AB Svenska Metallverken for a reducing oven within a tight-fitting vault that accepts extremely hot gases from the process. Ordinarily these gases are too hot to be collected directly by the vault, but a cleverly-designed cooling system (by which the hot gases are cooled by water) and a water-to-steam evaporator reduce the exhaust temperature acceptably. The exhaust drops in temperature from 1000^{o}C to 200^{o}C, generating useful steam in the process. In the case studied by Wene, this steam is delivered to a paper factory 300 meters from the steel mill. In all, about 20,000-25,000 tonnes/year of oil are saved by using this waste heat.

Equally important, the reduction in direct radiation within the steel factory improves the work environment there, and less air is sucked in towards the oven. Finally, the amount of dust arising from the process is lowered to satisfy the norms in effect. In all, energy is saved, the work environment is improved and the factory has more control over the pollution ultimately emitted in the entire process.

Other environmentally-motivated improvements include mechanization, especially for lifting heavy objects. Wene notes that this energy is relatively small compared to process energy or other electric drive (including fans). Lighting, too, is mentioned as an ingredient in a better work environment. Improvements in the placing of luminaires (as well as in the lumen/watt ratio of lights themselves) have allowed considerable improvement in lighting conditions in factories at a small increase in total electricity use (which in any case is still small compared to overall electricity use in factories). Here it should be pointed out that in the US and central European countries, overlighting in office buildings has become a severe problem, since waste heat produced must be exhausted, often at great expense, via circulators or chillers.

How much does the comfortable work environment cost in energy terms? Wene estimates a total of 2.5-4.5 TWh of electricity for all of Swedish industry, less than 2 percent of total Swedish energy use in 1985. To this must be added a significant quantity of oil for warming factories in Sweden, consumption barely necessary in other countries. Overall, the energy requirements for the workplace are moderate.

BOX 5. INDOOR AIR POLLUTION

While much attention has been paid to outdoor air quality, measurements in several countries during the past few years indicate that indoor air is subject to contamination from several kinds of pollutants (Table 4 in the text). Some of this population is chronic, arising from the very materials from which structures are made, such as stone (radium-radon), plastics (formaldehyde), or particulates (plaster). Another obvious source of indoor air pollution is people. This odor problem was noted in an experiment with an extremely tight house in Denmark. Finally there are key time-dependent indoor air pollution problems arising in connection with cooking (using both gas and electricity) and smoking. In the former case an interaction between the gas flame and the cooking utensil produces concentrations of nitrogen oxides and CO_2 beyond what combustion itself would produce. Moreover some homes with indoor gas or coal burning heaters that use indoor air for combustion also produce undesirable concentrations of these pollutants. Finally all cooking processes produce contaminants from the foods that are cooked. As Hollowell (1979) shows, the concentration of these contaminants can become much higher than outdoors under certain conditions. At other times the quality of indoor air can be better than outdoor air.

What has frustrated conservation research is the obvious connection between indoor air quality and ventilation. Roughly speaking, the voluntary (mechanical) ventilation of large buildings or homes (common, for example, in Sweden) or the involuntary infiltration of all structures by outdoor air normally keeps the concentrations of undesirable pollutants

NITROGEN DIOXIDE CONCENTRATIONS IN A TEST KITCHEN

AIR EXCHANGE RATE IN KITCHEN	NO_2 IN KITCHEN*
.24 ach (No stove vent)	1.2 ppm
1.0 ach (With hood vent above stove)	0.80 ppm
2.5 ach (Stove hood vent with fan at 50 CFM)	0.40 ppm
7.0 ach (Stove hood vent with fan at 140 CFM)	0.10 ppm
Outside during test	0.03 ppm

*(1-hour average concentrations in kitchen with a gas oven on for 1 hour at 350° F)

Typical ambient outside NO_2 concentrations	0.02 ppm (clean) - 0.30 ppm (heavy pollution)
Promulgated and recommended 1-hour NO_2 standards	0.20 - 0.40 ppm
ASHRAE ventilation requirements for kitchens in single family residential houses	**Recommended:** 30 - 50 CFM (ASHRAE 62-73)/person **Minimum:** 20 CFM (ASHRAE 90 - 75)/person ach = Air change/hour

well below short term or long term exposure thresholds that are commonly accepted as tolerance limits. But reducing ventilation can radically increase the concentration of pollutants.

Hollowel's work (see table) shows that lack of proper ventilation can increase the level of NO_2 in a gas stove kitchen by a factor of 40 compared with outdoors and by a factor of 12 compared with a well ventilated kitchen. Levels of ventilation that are desirable for energy conservation--less than one air change per hour (ACH) would increase the level of NO_2 to levels generating concern.

Indeed it was reported in Hollowel (Melia, et al. 1977; Brit. Med. J. 2, 149) that children in families cooking with gas had a somewhat higher incidence of respiratory illness than those in similar families using electricity. Accounting was included for differences in socio-economic factors, and to a certain extent smoking, which admittedly is another important factor in the health-indoor air relationship.* Clearly, indoor air must be monitored carefully as the air exchange rates are brought down.

Hollowel notes problems with concentrations of two other pollutants, formaldehyde (arising typically from the glue used in particle board) and radioactive decay products of radon gas, a product of the decay of naturally occurring radium. These decay products, especially

* The State of California recently defeated an initiative that would have required separation of smokers from non-smokers in most public places. Such an ordinance has been effective in Minnesota and in Berkeley, California. By contrast, some European airlines mix smokers and non-smokers by seating one group to the left, one to the right on narrow-bodied airlines (Lufthansa, KLM), and recent changes in classes of service among major American airlines has also resulted in much more mixing of smokers and non-smokers. Society's attitude towards the importance of indoor air quality is at best mixed.

polonium and lead, can find their way into aerosols and ultimately deposit their alpha particles in the lungs of inhabitants. Work in Sweden suggests that this problem, aggravated synergistically by cigarette smoking, may lead to several hundred lung cancers per year because of the exceptionally tight construction of homes there, homes often made with materials particularly rich in radium. One Swedish study even examined the possibility that radon in ground and drinking waters enters structures (for example during bathing).

The hazards of indoor air pollution must be examined carefully as we tighten up buildings to save energy. Recall, however, that saving energy in buildings by improving thermal integrity itself has benefits beyond the financial savings in fuel and electricity, namely the increases in confort and reductions in drafts and moisture in indoor air that themselves have been traditional sources of colds and other health problems in the winter months. But what is available to ameliorate the problem of indoor air pollution?

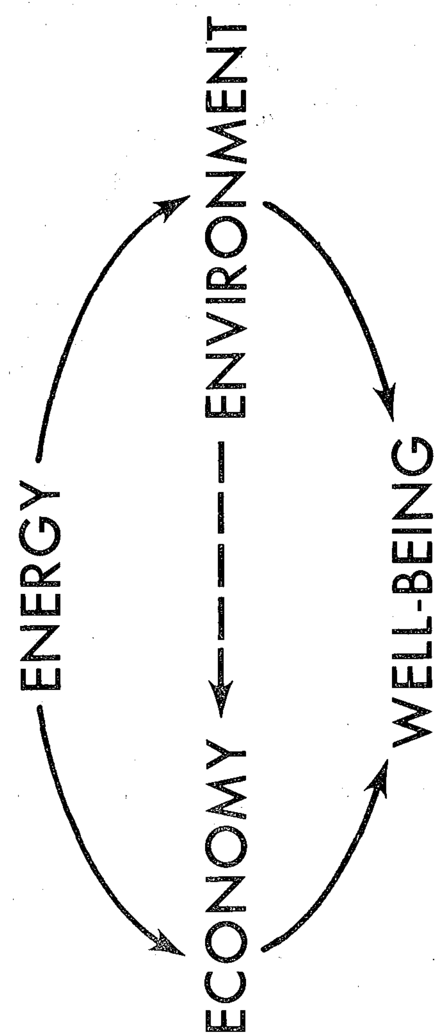
For one thing, Hollowel finds many technical solutions, especially those employing heat exchangers. One Canadian group (Besant et al., 1977; to appear in the "Proc. of 1977 Dubrovnik Int'l Conference on Heat and Mass Transfer in Buildings") has advanced design concepts for low-cost systems. Many international firms (Bahco, Flaekt, Atlas Copco in Sweden; Mitsubushi in Japan) have announced plans to market low-cost heat exchangers for smaller buildings. Using heat exchangers rather than involuntary infiltration to reduce energy losses and clean indoor air has several advantages beyond energy conservation; reduction of indoor air pollution (by cleaning or by air exchange) control of the entry of outdoor pollutants; control of noise. The latter two advantages can be seen as environmental benefits from energy conservation when applied to buildings in cities, where air pollution and noise prevent occupants from ventilating with windows during moderate weather.

Finally, Hollowel notes, certain techniques may allow builders to seal off sources of indoor air pollution--hoods over the stove, coatings on stone or plastic building materials, better control of ground air leaking upwards into structures, ground air that may be relatively rich in radon.

Ultimately the balance between reduction of indoor air heat losses and environmental quality is economic--given a sensible standard of indoor air quality, conservation improvements will have to include measures that maintain or improve air quality. This may mean that resources that may have gone directly into energy-saving equipment may be partially diverted to air quality maintenance, though the "loss" in conservation potential is probably small.

Moreover, society's habits may change--more reliance on natural ventilation in moderate climates, somewhat lower indoor temperatures, less indoor smoking. All these adaptations would lessen the potential conflict between the need for energy conservation and the need for a clean indoor environment. A measureable amount of a country's energy consumption is used for heating or cooling of the extra air required in buildings where smoking is permitted--an amount possibly as great as 1% of total national consumption for the U. S. (A. Rosenfeld, Lawrence Berkeley Laboratory, unpublished estimate).

0 0 0 0 5 1 0 2 5 7 9



XBL 759-4095

Fig. 1

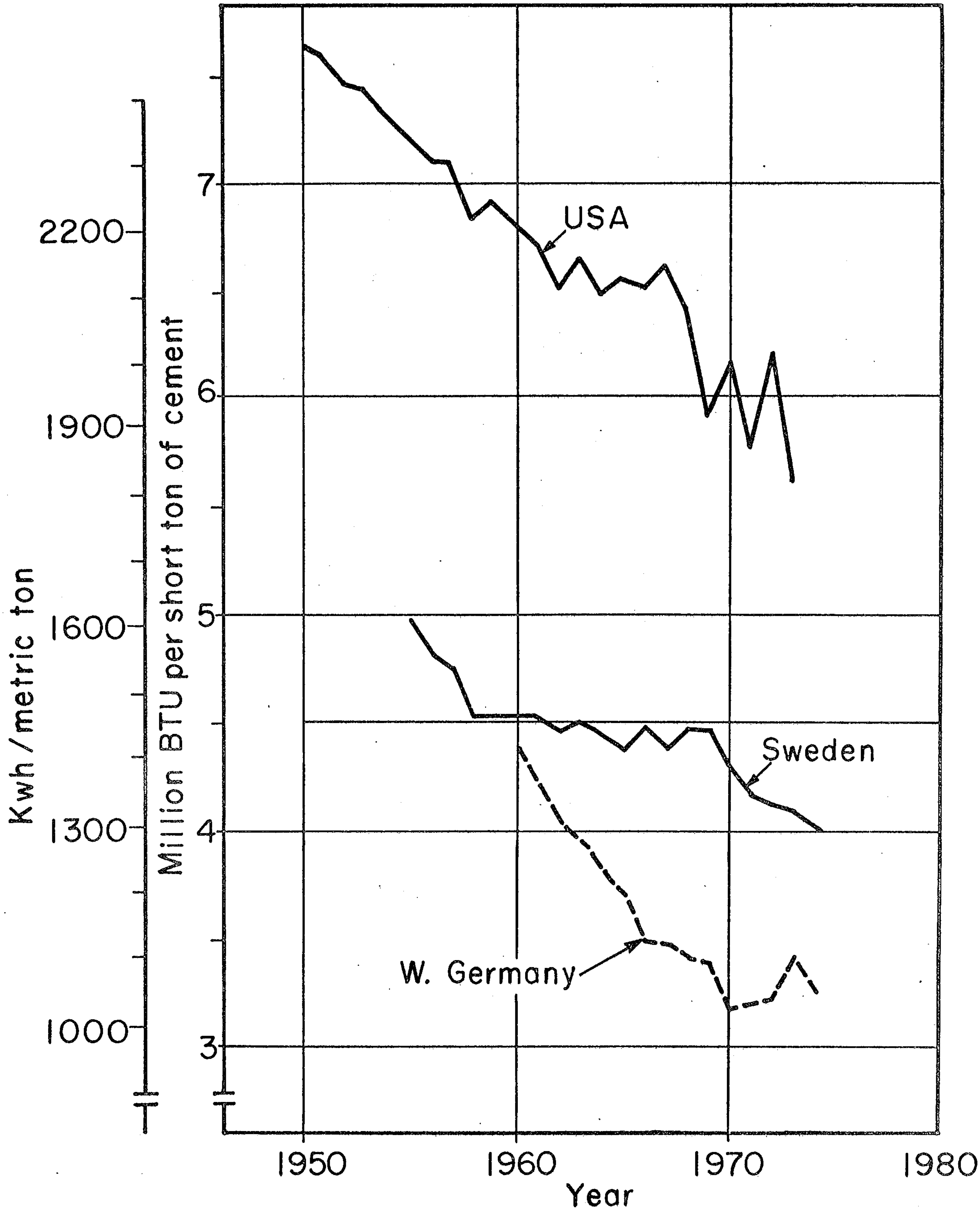


Fig. 2

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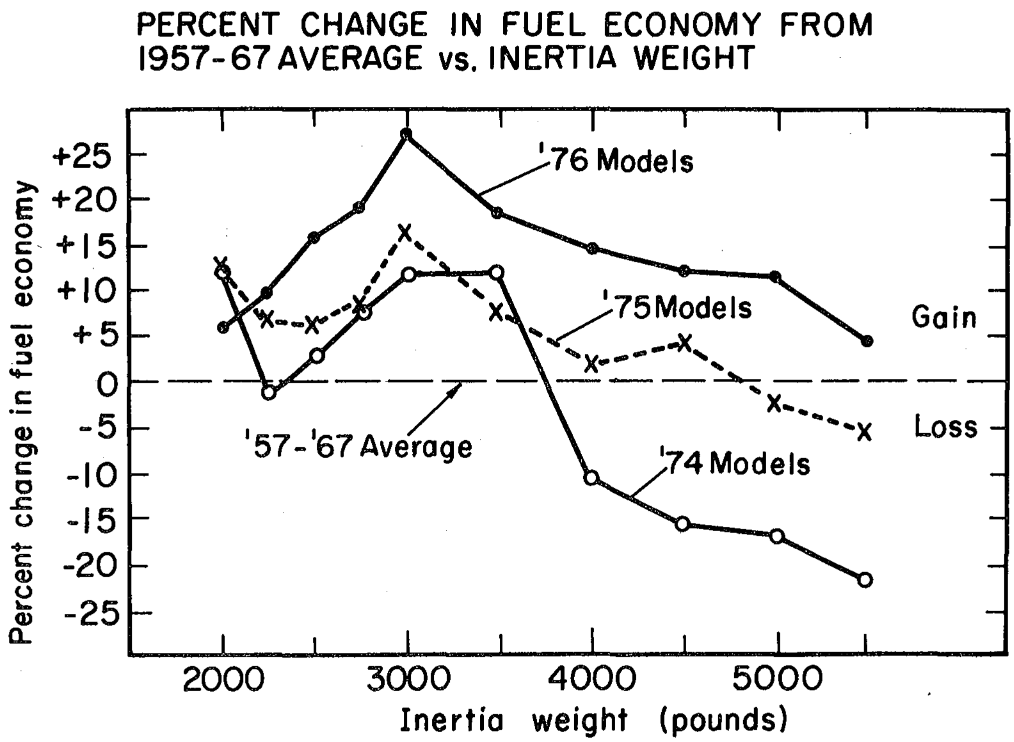

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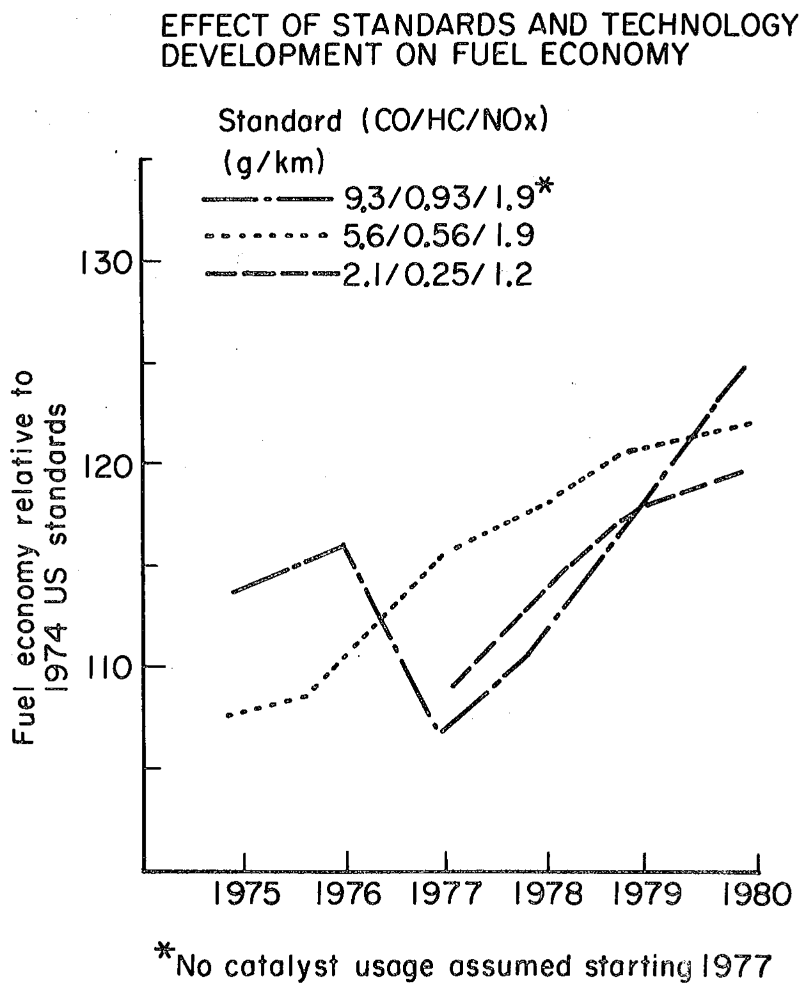
Fig. 3(a)



XBL7812-12353

Fig. 3(b)

0 0 0 0 5 1 0 2 5 8 0

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