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Lee Schipper and Joel Darmstadter

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I. INTRODUCTION

The importance of energy derives from its input to production and consumption activities in an economy, activities that in turn derive from society's choices for goods and services. To provide these goods and services, energy is used in combination with other resources. Historically, energy prices have been relatively low, and falling, relative to other prices. Yet whether we are talking about mechanized industrial or agricultural processes, freight or passenger transport, or the illumination and heating of commercial and residential structures, the use of fuels and electricity is clearly a critical element in the social and economic life of a nation. Consequently, it is not surprising that to many the notion of a reduction, or a reduced growth rate, in energy use produces anxiety about a concurrent constraint on the level or quality of economic activity and material standard of living.

On the other hand, a great many investigations of energy use(1) have now shown that reductions in the amount of energy use per unit of economic activity are not only technologically possible, but are desirable according to economic and other criteria. These reductions in energy intensity belong to a set of activities known as energy conservation. In this essay we will probe the nature of energy conservation. First, we review the ways in which we measure energy use and efficiency.

II. MEASURING ENERGY USE AND CONSERVATION

Some Basic Notions

Energy conservation, in the sense used in this report, describes ways to enable unimpaired provision of goods and services while economizing on the use of energy resources. Emphasis on the economizing nature of energy conservation implies that such actions are undertaken with a conscious regard for their cost implications. One manifestation of energy-conserving actions may be a reduction, over time, in the ratio of energy consumption to output (nationally or for a specific activity within the economy), or differences at any point in time in the energy output relationships (energy/GNP is such a measure) among countries or among activities. Energy demand relative to economic output can be reduced in two ways: a) using less energy per unit of a specific good or service, and b) shifts towards a less energy-intensive mix of goods and services. However, the composition of goods and services in an economy can shift independent of factors related to energy. It is important to recognize that changes over time in the energy/GNP ratio, or lower ratios in one country compared to another can occur for reasons unrelated to conservation, and indeed, can obscure developments that are genuinely conserving in character.

It is clear that analysis of conservation compels us to deal with units of energy input, on the one hand, and units of output or activity, on the other. By the latter we mean aggregative values like GNP or industrial value added, or more specific physical measures such as passenger-miles of travel or tons of steel produced. The preferred energy input measure is primary energy resource inputs into the economy (e.g., crude oil) even though a particular conserving action may take place at the end-use consumption stage or somewhere along the path from energy production, through transformation and delivery to final utilization. Thus, a saving of a unit of electricity in, say, electrolytic reduction signifies a saving of over 3 units of primary energy needed to generate electricity.

Conservation analysis, ideally, also considers the non-energy resources (labor, capital) which complement fuels and power in economic activity, changes in which frequently accompany changes in use of energy. We can more easily deal with this question in principle than we can empirically. A body of quantitative knowledge on energy vs non-energy inputs is only now developing. We discuss below some of the important parameters that allow us to evaluate the trade offs between energy and other resources. Evaluating these tradeoffs is, in a large way, the task of the CONAES Demand/Conservation Panel.

The concept of "intensity" or "energy efficiency" is subject to several interpretations. It is important to understand these differences and clarify the meaning of the term as it will be used in the balance of the discussion.

Energy Intensity

When we refer to the energy consumed per unit of output, we employ the term energy intensity. A ratio such as that of energy consumed to GNP, energy consumed per dollar of shipments in a particular industry, connotes energy intensity, as does a measure such as energy use/passenger mile. Additionally some analyses[2] focus not only on the energy expended in the activity in question, but include energy expenditures

"upstream" that were required to provide all the inputs, including energy itself, that were consumed in a process. Thus the energy intensity of automobile production, when such indirect uses away from the final assembly plant are considered, reflects the coal used to make steel, and the diesel fuel consumed to mine the coal. When conservation strategies are discussed that entail changing the techniques of energy use in a process, direct intensities are usually sufficient as measurements of changes in energy use. Where however our conservation technique employs significant amounts of resources that themselves are energy intensive (such as substituting the basic oxygen process or the electric scrap furnace for the blast furnace in steel making) indirect energy requirements should ideally be included. Finally, changes in the patterns of consumption of non-energy goods and services can alter the energy requirements of the economy as a whole; these changes must also be considered on a direct + indirect basis, since the consumption of a book implies energy consumption in many industries upstream from the printing press, such as the trucking industry, the chemical industry (ink) and the paper industry, which itself buys chemicals for pulping and paper making. Fortunately a good body of data exists that allow us to evaluate the most important total energy impacts of consumption decisions.[2]

However, a word of caution is in order regarding the measurement of energy used and conservation. Certainly we would agree that when the energy intensity of a given activity is decreased (insulating homes) that energy is being conserved. We will suggest herein that if homeowners lower thermostats energy conservation is also being practiced. If people prefer larger homes, which for a given level of insulation require more heating fuel than smaller homes, it is certainly improper to say that energy is being "wasted" because homes are larger. If, on the other hand, the newer homes require significantly less energy per square meter per degree day, even if more total energy is required, then we may label these homes as "energy conserving"! Thus measuring conservation and waste requires knowledge of the intensities of energy use and the type of economic activity included, not merely "before/after" quantities of energy being used.

Concern has been raised[2] that whenever energy and money is saved, the money saved, when respent, will generate as much (or more) demand for energy as before. However, a little consideration shows this to be a minor effect. The greatest energy saving options either save many BTU's and return a savings after substituted resources (which are far less energy intensive than energy) are employed. Other options save fewer BTU/$ saved because the energy savings come about through behavioral/preference changes that employ no substitute resources directly. Unless the monetary savings in the second class of examples are respent for the same kind of energy (or a less expensive, and therefore more energy-intensive form) the total amount of energy demanded by respending should be only a small fraction of that saved. In the first case, of course, all of the monetary savings are not available to the saver, a portion being taken by the conservation option.

As energy costs rise, of course, the monetary savings will be larger, but so will the energy costs embodied in all products, until producers also adjust by conserving energy. Thus it seems doubtful that saved dollars can generate nearly as much demand as before (see Ref. 3).

Certainly some lifestyle or preference changes that change the personal consumption mix may actually save money that will be respent in relatively energy intensive ways. Again, however, increased energy costs will affect the prices for energy intensive goods and services, as well as stimulating efforts for resource substitution in the respective industry/services branches. More important, the consumer presumably has made the lifestyle/preference change because she prefers the new consumption mix, given the spread of prices for all goods and services. Bearing this in mind we may well want to dismiss any fears that when all costs and intensities have changed, the amount of energy "conserved" is less than expected, or even negative because the consumer is expressing her preferences through the marketplace using many valuation procedures, and not simply a standard derived from the consideration of energy alone.

Efficiency

While "energy intensity" denotes an objective measure of energy use, its inverse, "energy efficiency" connotes both objective and judgmental aspects of use. It is worth reviewing the various uses of "efficiency" in the energy field, in order to sort out those meanings we wish to imply herein.

Certainly we know that energy cannot be destroyed (or created), but the quality of energy, the ability of a given amount of energy to perform work, can be and is constantly being degraded in virtually any and every energy process whereby energy changes form.

Thermodynamics provides an unambigious measure of the minimum amount of energy quality that must be sacrificed to perform a task. We can compare the energy (as fuel or electricity) actually used in performing a task with the minimum required by thermodynamics. The ratio of energy actually used to the minimum required gives a dimensionless measure of the physical intensity of energy use, revealing how far from nature's limits a particular use of energy is. Applied purely within this thermodynamic framework, efficiency is a measure of the inverse of intensity — the higher the efficiency, the lower the intensity.

The tasks for which energy is used, however, are not unique, in the sense that they may be modified to further the production of the amenity for which energy is required. Thus, recycled aluminum may be substituted for aluminum produced from virgin ore. The task required for using this recycled scrap is significantly different, and less energy consuming, than those employed when ore is used. Or a home may be insulated so that heat inside leaks out more slowly. The task for which energy is consumed, maintaining a temperature difference between inside and out, is now modified since the heat loss is lower for a given temperature difference. Thus, thermodynamics, while a good guide to the minimal energy requirements of specific tasks, does not limit us as to which tasks we must perform.

It is instructive to note that the most important thermodynamic variable (for energy conservation considerations) is temperature difference. The temperature difference that the combustion of fuel

can produce is a measure of the quality of energy available from that fuel. Electricity, which is of the highest quality, can produce extremely high temperatures. Similarly, the amount of energy quality or work that must be employed to perform a task varies directly with the temperature difference embodied in that task (with mechanical work considered as infinite quality energy). Conversely, the amount of mechanical work that can be extracted from a body of heat depends on the difference in the temperature of that body and the temperature of a cooler reservoir to which heat can be rejected.

However, 30% of all fuel or electricity used in the economy performs tasks that change temperatures by less than 80°C, while another sixth produces process steam at 100-400°C and an additional sixth produces truly high temperature process heat, often with exhaust gases at temperatures higher than the application. The amount of fuel or electricity used for the low and middle temperature tasks is many times the minimum required by thermodynamics — hence, one reason (though not the only one) why the efficiency of energy use is low. Surprisingly, the amount of fuel used to produce electricity is only 3 times the minimum required; thermodynamically, electric power generation is relatively efficient.

It has been suggested, therefore, that by considering both the source of energy and the use, we can effect more of a close match between the quality of the supply and the quality of the use. Space heating, and some industrial uses of heat at temperatures only slightly higher than the average yearly outdoor temperature, are ideally suited to the heat that can be collected from the sun; or the same uses can be met by hot water emerging as "waste" today from powerplants. Where higher (but not the highest) temperatures are required, extremely hot combustion gases can be "cooled" to the required temperatures by expansion through a gas turbine. This provides electricity at a rate such that nearly 80% of the quantity of energy that is lost to the turbine appears as electricity, rather than 35%, a figure typical of the 1970's for large single purpose powerplants. Thus one way to "conserve" uses thermodynamics as a guide, whereby we consider both the energy source, its quality and quantity, and the task for which energy is required.

We can relate thermodynamics into technology by looking at the designs of existing (and proposed) energy-using devices. This prompts another definition of intensity, which relates the energy consumed to the physical output produced. Thus we might ask about the energy consumed per hour of cooling for a specific air conditioner or refrigerator, the fuel consumed per square meter per degree day for the heating system (and shell) of a home, the energy requirements of a vehicle-mile (of auto transport) or the energy used to produce a ton of steel. These design intensities, and their inverses (design efficiencies) are again objective and useful measures that relate energy use to tasks and amenities.

We might at this point pause and describe two steel making processes —one, an older blast furnace using, say, 16×10^6 BTU of heat per ton of raw steel produced, the other using only 10×10^6 BTU/ton. (These numbers are not exact, only illustrative).

The furnace with the lower design intensity is noted to have the following features —

1. The sides are thicker and better insulated.

2. Maintenance on the fuel combustion unit is done more frequently.
3. The heating up of the furnace is timed more carefully to match the time that the charge of iron is in place.
4. Small pieces of insulation around movable parts are constantly being replaced as they wear out.
5. The hot gases emerging from the furnace are used to provide electricity — the waste heat from this process is then piped to another area to heat quarters where offices are located (or alternatively to preheat the next charge).

In this description of "energy conserving" technologies we recognize that we have substituted capital (thicker walls), labor (maintenance), information (timing), materials (replacement of worn out insulation more often) and thermodynamic optimization (use of the energy quality in "waste" heat as a resource in another process) for energy. We have changed the production process, thereby conserving energy. But how do we know that this set of substitutions is desirable? That is, should we be "conserving" energy as we have done?

The Issue of Waste

The comparison of processes outlined above raises a key issue in the debate over conservation: What is 'waste'? Is the more energy intensive furnace necessarily wasteful? Or consider the household that trades a conventional refrigeration for a "frost free" model. In return for an unchanged level of cooling and a reduced level of effort required to maintain the refrigerator, the household uses more electricity, with subsequent higher electricity bills. This example is, of course, simple and quite self-evident - what we are witnessing is not an irrational and costly temptation to gadgetry but a measurable trade off of energy for time and drudgery. Similarly substitution of automatic transmissions for manual increases driving energy requirements but saves effort. Yet many, if not most drivers preferred automatic transmissions, at least during the decade when gasoline prices fell and autos got larger.

But it is probably unjust for society to label these switches towards increased energy intensity as "wasteful". This is because energy use (or intensity) alone is not a sufficient yardstick with which to measure optimality — or waste. One person's frivolity may be another's necessity, last year's indulgence this year's need. Some forms of energy use may rightly be deemed wasteful, if, then the users are informed of what is occuring (and at what cost), they ignore steps that decrease costs. But how are we otherwise to judge the limits of legitimate, "non-wasteful" energy consumption? This problem is especially acute when the occupants of buildings do not directly pay for the energy services, such as white collar workers or customers in stores.

It may well be that in addition to specification or least cost solutions to energy uses (insulation, perhaps enforced by a building code) that society acts to provide information about, and perhaps rewards for, changes in preferences and lifestyles that in fact reduce energy needs, without actually enforcing a national standard of waste vs. need. That is, each individual consumer should be allowed to divide up her/his energy uses (and other resources uses) into a spectrum of "needs" and "non-needs" AND act accordingly. Certainly energy using activities will often carry with them popular judgements regarding

energy frugality or energy profligacy, but intimations regarding "waste" had best be guarded. Indeed we suspect that the difficulties in judging preferences and lifestyles may have caused most previous energy use studies to concentrate heavily on possibilities for technical fixes, leaving questions of behavior and tastes for the individual to decide.

Sometimes, however, waste can be built into the energy use system technology. Consider district heating systems, or central apartment boilers, in Sweden. These systems are not metered on an apartment by apartment basis, hence no individual has the incentive to regulate temperature in accordance with her demand or preference curve (i.e., the marginal cost of an additional unit of heat is zero in the short run). In addition to this economic problem, the systems themselves are not easily regulated, with thermostats measuring room temperature virtually unknown. The hot water radiators can either be on or off. Thus even if apartments had been billed directly, occupants would have had difficulty controlling heat. However, most Swedes developed a technique for controlling temperatures — opening the windows!! As a result of these technical difficulties, use of energy for heat in Swedish apartments (which are well insulated anyway) is nearly as high per capita (or per square meter) as in single family dwellings, even though in theory heat use should be considerably lower. The heating situation described herein might rightfully be described as "wasteful", so much so that some of the fuel savings allowed by district heating are erased by the high levels of consumption in the apartments themselves.(4)

It may seem at first unfortunate that we reject energy intensity as a yardstick for measuring waste, because intensity is well defined for any energy use. Similarly the thermodynamic or design efficiency of a particular system, is a useful and objective piece of information. But these measures are not sufficient for deciding whether a practice is wasteful, (i.e., whether we can conserve energy) because they ignore other resources. In order to decide whether conservation is merited we turn to a broader picture of resource use, employing economic yardsticks to judge the overall efficiency of energy use.

III. WHAT IS ENERGY CONSERVATION?

Economic Efficiency

As long as energy is used along with other resources to further economic or personal welfare it seems logical to employ the same yardstick for energy conservation that is used in other resource decisions. We will acknowledge below that there are many imperfections in the measuring process that make economic evaluations of energy use decisions complicated. Nevertheless we will begin by assuming that the force that drives both consumers and producers toward energy conservation is the perception — or calculation — that they can improve their welfare by carrying out changes in the way energy is used. Conservation is a means to greater welfare, not an end in itself. The most impelling factor in inducing conservation action is the cost of not conserving. Given energy price increases of the magnitude witnessed in recent years, energy users, acting rationally, are likely to seek ways for mitigating the effects of these cost increases so as to maximize income under prevailing prices. When the cost of any input to a product or service increases, users will, with time and greater or lesser success, respond by attempting to reoptimize their consumption/production by finding substitute resources for those factors that increase cost. One can, for example, substitute one form of energy for another, although the greater the substitutability (and the freer the market circumstances) the more are all energy prices likely to move in tandem.

Consider, however, the substitution of non-energy resources for energy. This substitution comes about in three ways (see Fig. 1):

1. Users substitute other resources for energy in the production of that amenity or product for which energy is required; i.e., adding insulation reduces the energy needs (and costs) of proving indoor temperature.

2. Users change their habits, preferences, or operating procedures so as to reduce direct energy requirements; i.e., turning back thermostats or increasing maintenance of industrial boilers.

3. Users come to consume a mix of goods and services that is intrinsically less energy demanding; i.e., less distant vacation travel.

It is these classes of welfare/profit/income maximizing responses that we define as energy conservation.*

Curtailment

The boundary conditions for actions or policies that fall within the scope of energy conservation and those that do not are hard to specify unambiguously. Curtailment, a policy, is on this boundary. It involves the use of a number of policies to bring about rapid reductions in energy demand while minimizing adverse economic and social impacts. These actions can be implemented rapidly and are primarily for short-term application, although they may have lasting effects. The goal of curtailment can be to effect rapid demand reduction in energy use in response to sudden shortfalls in energy supply, with minimum social and economic dislocation. Curtailment involves developing contingency procedures for various possible future emergencies. Such tools as rationing, allocation schemes, energy price controls and mandatory use patterns are brought into play in a carefully planned policy package. Planning is necessary since many possible secondary effects are counter-intuitive and may even be

*In an enlightening discussion, McDonald[5] advances a similar definition, referring to the maximization of the present worth of resources.

counterproductive. Indeed, "heroic" curtailment measures very often have a detrimental effect on well-being by restricting the availability of valuable goods and services and by reducing economic productivity through the misallocation of scarce resources. We deem measures to limit economic growth in the interest of saving energy (curtailment) as outside our conservation framework, much as a moderation of economic growth may be thought by some to have virtue in its own right, and much as some regard this as a legitimate part of conservation. A less clear-cut case involves certain types of energy curtailment policies. The 55 MPH speed limit, when enacted during the 1973-74 oil crisis, was probably though by the public to intrude into, rather than abet, its perceived welfare— not a conservation action by our test of unchanged or enhanced welfare. In time, however, society may not only regard the 55 MPH restriction as compatible with its welfare but actually conducive to greater welfare because of reduced accident risks.[6]

Fuel Switching

Switching demand to more plentiful fuels can result in an overall economic benefit to society by relieving the pressures on less abundant energy resources, thereby avoiding shortages. A key objective in fuel switching is to minimize ancillary requirements by retaining the large installed conventional supply system (e.g., power plants, pipelines) and end-use capacity (e.g., gas heated homes). Some conceptions of conservation allow for a saving in one unit of fuel (say, natural gas) to offset the greater use of another (say, coal) — total BTUs remaining unchanged.

We note, too, that the cost/BTU alone is probably an insufficient indicator of the desirability of a fuel switch, even if the price reflects the real scarcity of the fuel. This is because different fuels can perform different tasks, at different physical efficiencies — witness the switch from coal to a more expensive but more productive fuel, diesel oil, in locomotives. However, one kind of fuel switching — substituting renewable resources such as solar energy or wind — for non-renewable resources, is considered by us to be energy conserving in character.

Other Aspects

The discussion of conservation is often clouded by confusion among several important aspects of changing patterns of energy use: the social, political, and economic impacts of the conditions that make conservation feasible or desirable; the effects of conservation strategies and changing energy use patterns themselves; and the effects of policies designed to aid, stimulate, or implement energy conservation strategies. These issues are important and should be analyzed separately and in combination. However, the existence of a conservation option does not necessarily make that option desirable; the desirability of a strategy does not automatically make policies designed to aid or speed implementation politically or socially desirable. Conversely, the possible negative consequences of conditions (such as higher energy prices) that stimulate conservation does not mean that strategies that will be implemented or use new patterns that will occur themselves are automatically bad.

What is important to bear in mind is that conservation, as we are defining it, is essentially a response to economic, environmental, or social concerns arising from resources and their use. When, in responding to these concerns, we can raise both economic and technical efficiency, we are "conserving" energy. Conservation is not an end in itself, but instead a means toward furthering economic and social goals that involve resource use. Measuring these goals, whether by noting changes in income or Gross National Product, or improvements in environmental quality, is by no means an easy, unambiguous task. Nevertheless we will see that virtually all the important energy conservation strategies that lead to reductions in the energy intensities of activities involve changes in resource use or behaviour that are well defined. Once these strategies are discussed and defined, the debate over conservation turns to the problem of expectations: How much conservation might take place, today and in the future; what institutional, economic, or technical barriers to conservation might appear; and what are the social and environemntal consequences of conservation strategies, once implemented? We turn to the first question, one which occupies a great deal of the time of the CONAES Demand/Conservation panel.

IV. HOW MUCH CAN BE "CONSERVED"? HOW MUCH SHOULD BE CONSERVED?

Substitutions

To probe the motivating impulses for energy conservation more closely, recall that energy is but one of many resources used in the economy. While there are some energy conserving practices that are essentially costless — unaccompanied by increased outlays for other resources and involving no significant intrusion into living standards or behaviour — there are also many options that do involve a significant substitution of non-energy resources for energy. It is necessary, therefore, to consider the total resource cost implications — and not merely the energy consequences — of changed energy using practices. It is insufficient, for example, to argue that, in the example given above, one type of blast furnace is "better" than another simply because less energy is required. If, for example, the extra labor and capital required exceed the (non-energy) resources freed from the production in the energy sector, then resources will have to be shifted from elsewhere in the economy with the result that there may be a diminution of total production. Or, a steam electric power plant might produce more electricity per unit of fuel if the steam inlet temperature were increased. But this could call for more expensive materials. Is the fuel saved worth the extra capital cost of heat resistance? The key is to consider the total resource cost implications of the alternatives, using the costs of input resources as guides to resource use.

We acknowledge readily that prices and costs may be distorted for a variety of reasons — market or tax subsidies to fuel producers, failure to include environmental costs, price controls, and so forth. Nevertheless, this cost framework is a useful starting point.

A similar issue arises when the energy implications of consumption decisions are considered: Are returnable containers more "efficient" than throwaways solely because they require less energy per filling? Are cotton ("natural") fabrics more "efficient" than synthetics because they apparently require less energy to manufacture? Or are the other resources needed to produce cotton — land, water, pesticides, herbicides — also to be compared with the energy requirements of feedstocks that are turned into synthetic fibers? We suggest that all resources, not merely energy, be considered in consumption decisions.

Where substitutions are concerned, the economic procedures for evaluating "desirability" are well known. One evaluates the investment and operating costs of alternatives, discounting future costs and benefits to the present, choosing the alternative with minimum total cost — for example, retrofitting a house with up-graded insulation if the discounted fuel savings exceed the insulation investment over its expected life. Particularly important to this evaluation is both the future assumed price of energy, the assumed trend in the price, and the assumed discount rate. Marginal energy costs significantly higher than average energy costs — as seems to be the case with natural gas — raise a particularly vexing problem, since the individual use lacks the "signals" that are socially optimal.

One effective way of portraying a number of points made in this discussion is by means of Figure 2. This graph[7] shows how a succession of technical-design improvements in refrigerator-freezer units yields energy savings as a direct function of price. The break-even point between energy savings and increased price — not shown in the chart — depends of course on actual and anticipated energy prices, discount rates, and life expectancy of the equipment. Figure 2 also

enables us to ponder the blurred boundary between technical improvements versus behavioural adaptation in energy conservation. Thus, point #5 on the graph indicates that resource to a manual-defrost model results in both reduced energy use and lower purchase price. But reversion to such a model presupposes a willingness for behavioural adaptation in the interest of conserving energy that we have no reason to suppose exists; defrosting refrigerators is a disagreeable task. By contrast, Figure 3 — illustrating energy savings achievable by the relatively simple procedure of manually or automatically setting back night thermostat settings[8] — describes an uncomplicated energy savings behavioural act, requiring no "technical fix" and unlikely to conflict with a consumer's sense of well-being. We do not wish to imply, however, that these savings will be necessarily realized, but we deem quantification of the potential savings — and discussion of the behavioural implications — an essential ingredient in energy conservation planning and R & D.

Figure 2 presents us with an opportunity to compare the capital cost of conservation with that of new supplies. If all the substitutions in the Oak Ridge model are employed, the refrigerator will require about 100 watts less of average electric power, at an initial cost of $75, or $750 per kilowatt. By contrast, most new capacity in the electric supply system (counting generation and transmission) costs considerably greater than $750/kilowatt, and takes many years to be installed, the carrrying costs of construction included in the capitalization. Since the refrigerator options pay back in a few years (at 3¢/kilowatt hour) the user can easily afford to reinvest in conservation when the refrigerator wears out in ten to fifteen years, a period short compared to the 30 year life of a power plant. Thus conservation as substitution saves resources, including capital, since both the capital and life cycle costs of producing an amenity, 17 cubic feet of coolth, are reduced by conservation. The rate of return on these substitutions, when taken together, is in excess of 30% per annum (compared to 3¢/kWh) exceeding not only the rate of return given to power companies, but also the interest rates on even the most expensive consumer credit. At higher average electricity costs the rate of return on conservation becomes even more attractive; it is reasonable to expect that (in the absence of a performance standard that requires that the cost effective options be included on all refrigerators) the proportion of "energy conserving" refrigerators sold will rise as the rate of return rises. That the substitutions modeled in Fig. 1 are already economic for virtually everyone is no guarantee that they will be demanded by refrigerator buyers, especially if the first cost/life cycle-cost tradeoff is not presented clearly.* It should be clear, however, that as electricity prices move upward more and more consumers will take advantage of the resource substitutions available. Once the conservation discussion agrees on the technology and economics of this (or any other) substitution, the investigation can proceed to problems of response and implementation.

The refrigerator model illustrates the interaction between a cost effective conservation option and the future need for new energy supplies. If all refrigerators in place in 1990 employed the modeled technology, a capacity savings of approximately 8000 MW of average power, generated by about 13,000 MW of installed base loaded capacity (at 60% capacity

*We note that at least one electric utility (Pacific Gas & Electric, San Francisco) now names brands and models of energy saving appliances, allowing the consumer to move from the theoretical world of energy conservation into the arena of a well informed purchase.

factor), would not be necessary.* While these results are only approximate, they allow us to estimate the savings in total resources, including environmental costs (fewer power plants, strip mines, emissions), that one single "technical fix" might allow. And we recall that the list of fixes for frost-free refrigerators is by no means exhausted. An earlier study indicates a potential savings of 66% in energy intensity (versus about 50% from the Oak Ridge study).(9) How much of this potential is realized depends on the future price of electricity, and research and development in new techniques for improving heat transfer, insulation, air circulation, and other vital links between electricity and coolth. Certainly, too, the response of consumers must also be factored in.

We can further illustrate the supply/demand interaction by stringing together a group of strategies that conserve natural gas. These strategies which were modeled for California homes at the Lawrence Berkeley Laboratory,(10) involve both thermostat setbacks and simple insulation retrofit techniques.† In Figure 3, we have entered the savings in order of increasing investment/yearly energy unit saved. Using this scheme we can clearly see how conservation takes on the appearance of new supply, different options entering into the price schedule as the investment cost is allowed to rise.

If we then assume a desired rate of return, and an energy price, we can read off from the graph those options that satisfy the economic criterion of cost effectiveness from a consumer's point of view. We can see, in

*80×10^6 households savings 100 watts each, is a useful approximation.

†We note in passing that water heaters and space conditioning systems are adaptable to retrofit much more readily than refrigerators or other appliances.

addition, which options compare with new supply at the marginal supply cost, and we can further juggle interest rates to see how sensitive the comparison is to different rates among different customers (i.e., utilities versus homeowners). Finally, we can estimate the possible impact of energy taxes or internalization of environmental costs.

It is clear, for example, that homeowners who purchase natural gas at a controlled price ($1.50/mmBtu in parts of California, for example) might ignore all of the options, or adopt only those that affect hot water, simply foregoing the savings from attic insulation. Other consumers, however, might wish to take advantage of every option that offers a rate of return greater than that given by savings institutions. While extra attic insulation could increase the assessed value of the house, the dollar benefits from that insulation are not taxed at the margin, since they take the form of reduced taxable expenses, and therefore greater after-tax income. Furthermore, the interest on loans taken to buy insulation would be tax deductible. While we will not work out the details of these first and second order effects, we merely point out that they may enter into the deliberations of the individual consumer. However, it seems clear that the most important, zero order parameters are the price of energy relative to that of substitution, and the desired rate of return.

Thus, for consumers paying less than $3.00/mmBtu for natural gas, storm windows are clearly uneconomic (at a rate of return of 10%) and retrofit wall insulation is barely economic, depending on the desired rate of return. (Of course in new homes these features are much less capital-intensive). If prices were shifted upwards, through decontrol, marginal cost pricing, or an energy tax, then more consumers would come to find conservation economic <u>by their own criteria</u>, as the economic

returns increased. This should not, however, be interpreted as a statement, often made, that one "raises prices to achieve conservation"; nevertheless it is important to see the relationship between the relative price of energy and the desirability of substitutes.

This example also illustrates some of the policy dilemmas that face energy planners. In areas faced with natural gas curtailments, necessitating a switch to oil ($3/mmBtu at the margin), or electric heat ($4-8/mmBtu, depending on the system), or in areas faced with rolling in significant quantities of "new" gas supplies from liquefied or synthetic products, policy-making bodies might require that all homes be insulated up to the point where the marginal cost of saving another Btu (in the supply territory) is finally equal to that of new supply. A utility, for example, could be required to insulate the homes in its territory <u>before</u> investing in a synthetic gas scheme, the insulation counting in the rate base until consumers have paid back the utility for the installation. Mandated economic efficiency may seem distasteful to some, yet we often face a situation wherein the market signals cannot be straightened out in a short enough time to forestall or avoid a forced switch to more expensive supplies. Each consumer sees only his/her own stream of possible benefits from employing conservation, but no consumer directly perceives the benefit to the region of perhaps avoiding — or at least minimizing the impact of — considerably higher priced resources. This consideration is even more important when the collective benefits include environmental preservation that is hard to measure, or that falls in some other geographical location. Of course we are not arguing that conservation standards be applied without a careful evaluation of the quantifiable micro-elements of costs and benefits, or the implications of imposition of those standards. But it is clear that standards can assist society in the period of rising energy costs, and increased external costs of providing energy, by both internalizing some external costs and speeding the response of society to the direct costs themselves.*

Looking Ahead

We can produce conservation curves (or schedules) as shown in Fig. 4. If the curve of available conservation savings options rises steeply as a function of increase energy savings, then substitution possibilities are few and/or difficult; if the curve rises more gently then substitution possibilities are more accessible, and savings (in energy and total resources) are greater. As usual we can indicate the relevant energy price we are considering (average costs and marginal costs, with future price trends taken into account or ignored). The amount of energy we conserve, or "capture" can be seen as a rough function of its price. This information can supplement traditional aggregate elasticities of demand by identifying explicitly important substitutions. Indeed, one of the goals of energy conservation policy research is to identify and investigate these "conservation schedules", in order to identify the potential for energy conservation via substitution or systematic optimization based on thermodynamic matching. These potentials exist in optimal and suboptimal systems when prices are rising. In general, these options will present a relatively smooth curve with respect to energy price, especially those involving climate conditioning, appliances, and industrial processes. Similarly, technical options regarding transportation can also be modelled using this method, though care must be used in dealing with

*The role of standards in increasing the benefits of implementation is discussed in an enlightening paper by Linds and Nathans(11).

automobiles since size, comfort, and luxury are difficult to model from a technical standpoint, though the propulsion system, transmission and drive train, or tire systems are much simpler (and perhaps more well understood).

When our conservation investigation finds that conservation options offer energy savings at costs far less than the cost of fuel/electricity saved, then we can be confident of much improvement in energy use efficiency for those uses (relative to the past) than in areas where the cost of conservation rises rapidly to the marginal cost of energy production. Certainly, too, the rate of implementation and the rate of overcoming institutional barriers (two problems discussed elsewhere), will depend in part on the microeconomics of the systems in question. We emphasize that while these problems are crucial to the success of energy conservation, their presence as barriers to more efficient energy use should not be taken as an indication that the economy will not "conserve" energy.

At the same time these relationships, combined with knowledge of thermodynamics and existing technology, can be used as a guide to future research and development of energy conservation options. One goal of middle- and long-term conservation R & D can be thought of as reduction in the rise of Figure 4, making more conservation available at a given energy price. By instituting energy conserving practices that follow these economic guidelines, and by decreasing the amount of energy and other reserouces required to provide a unit of economic activity, we are, in essence, increasing the total productivity of the economy. This is true even if the resources that substitute for energy embody more labor than the energy replaced.* Furthermore, significant substitution of non-energy for energy can have an important effect on the price of energy, by allowing society to slow the rolling in of the marginally most expensive energy sources. This also allows for significantly longer development times for energy sources that are technically, financially, or environmentally risky or uncertain. Furthermore, our rate of use of these (an any other sources) will, at any given time, always be lower in the future than if we had not begun to use energy more sparingly. This eases environmental strains and adds more downward pressure on the average price of energy forms. At the same time "hurried" conservation efforts could encounter supply bottlenecks of their own, especially where certain labor skills or key materials are required. Fortunately many of the most important near-term conservation options involve changes in investment and design, such as the addition of a few inches of insulation to a structure or a switch to thicker walls, rather than a complete redesign of a system.

Moreover, we note that there is no limit to "conservation", at least not until we approach both thermodynamic limits and the exhaustion of our ingenuity to modify and redefine tasks. Conservation depends on the evolution of energy costs and technology. Thus, conservation is not a "one-time" option, but rather a continual re-evaluation of the mix of resource use that allows us to minimize total resource costs in achieving

*It has been noted elsewhere that this seems to be the case for conservation practices involving appliances, thermal integrity of structures and industrial processes, and furthermore, the re-spending of monetary savings that come from buying less energy (with a low labor intensity) and more non-energy-intensive goods and services, which on the average have a considerably higher labor intensity than energy, can slightly raise the employment requirements (and total production) in the economy (see Ref. 1 or 2).

an end. For this reason, conservation planners should look ahead to the future and perhaps avoid measures today that will foreclose even more beneficial practices in the future as energy prices and other resource costs change. If to save heat losses we restricted the amount of wall area that could be used for windows, we might deprive resourceful home builders or architects of a great resource — the incoming rays of sunlight, streaming in through large south-facing windows, which, with proper house shading, landscaping, and use of thermal mass in the house, can provide a large percentage of the seasonal heating needs of the house even before active solar collector systems are considered.

Our examples of substitution have been few in number, but an examination of the literature of conservation[1,6] shows them to be representative. We again remind readers that the existence of an option does not imply that it will be adopted, nor that undesirable side effects might not occur either as a result of the actions taken to assure implementation, or as a result of implementation itself. Nevertheless, the discussion of conservation must start with an examination of the bare technical possibilities, as we have shown here, and then proceed to the barriers to implementation.

On the other hand, we pointed out above that conservation measures are not limited to those substitutions that leave perceived amenity levels unchanged. The thermostat setback in Fig. 3 might send chills down many spines; some people prefer sleeping in warmer environments to a greater or lesser degree, depending of course on the relative price of maintaining that warmth. We note, too, that the substitutions that lower total amenity costs considerably might stimulate users to seek greater levels of the amenity in question, i.e., well insulated homes could be kept warmer than uninsulated homes for the same monthly cost. Conversely, consumers who accept or prefer cooler environments will find the benefits of substitutions reduced! This is because the change in thermostats reduces immediately the amount of energy used for heating, so installation of insulation, saving nearly a constant fraction of heating energy, returns benefits on a smaller base amount. It will be necessary for conservation researchers to explore the behavioral/substitution interaction further, since the consumer's demand (or preference) function for an amenity such as warmth may be a different function of energy price than the function relating substitution possibilities to energy price. This is often overlooked in conservation discussions — that the elasticities of demand and substitution may be different, and indeed masked in historical series that simple model aggregate energy consumption and average price paid. Because of the importance of the issue of behavior and preference we will now dwell briefly on that subject.

IV. BEYOND SUBSTITUTION - THE OTHER FORMS OF ENERGY CONSERVATION

The kind of change in energy use patterns that fosters a continued level of production of goods, services, or more generally amenities, with less energy at a total cost savings has come to be known as the technical fix. Fixes apply to both existing systems, through "leak plugging" (retrofitting) and to new systems, through optimization of resource inputs ("input juggling"). Technical fixes also include the task redefinition of thermodynamic optimization mentioned above. However, as the cost of providing an amenity rises, especially amenities for which energy is a most important input (such as space comfort), consumers of that amenity will, in addition to seeking substitution possibilities that ameliorate all or most of the increased cost, seek to maximize their total welfare by adjusting their preferences. Some may forego some other amenity (at constant income) in order to keep the energy related amenity available despite increased costs. Other consumers will forego some of the amenity for which energy is used, expressing a marginal preference for other consumption, given the new cost of energy. This means that some consumers will lower temperatures in winter (Fig. 3 above) and wear warmer clothes (whether or not they add insulation), drive fewer miles, or switch to considerably smaller autos. Furthermore, certain products, such as fertilizers and household chemical preparations, airline travel, metal cans and throwaway packaging will become less desirable to consumers because these kinds of products will increase in price faster than most others, because of increased energy prices. Subjective factors — not just income and price — certainly shape consumer habits. Still, there must exist a response to the price of energy that includes both implementation of technical fixes, as minimum-cost paths out of the situation caused by higher energy prices, and a rearranging of consumer preferences and expenditures towards less energy-intensive purchases, including reduced direct use of energy for travel and space conditioning.

Of course many of the preferences for, or acceptances of, changed energy use patterns can evolve from education and or dissemination of information on simple energy conserving practices. People may well come to prefer lower indoor thermostats in winter, shifting their demand curves for heat towards lower quantity at a given price. More important, they may learn to perform certain tasks that allow for energy savings at little or no cost for the time involved in carrying out the energy-saving task. Here we refer to practices such as shutting off unused lights, lowering hot water consumption where possible, putting up or removing storm windows, or combining short automobile trips (so as to reduce total distance travelled).

However, there are also more sophisticated behavior/preference changes that can have significant effects on energy needs for transportation and space conditioning — these include opening the shades in south and east facing windows in the morning; closing them as soon as insolation ceases; using movable shades in the summer to cut indoor temperatures; recycling materials; eliminating auto trips under 1 mile (where fuel intensity is 4 to 10 times the average for a given car because the engine is not warm). These changes in the way people use energy and material may be price motivated but require education, information, and motivation for successful implementation. Particularly

important is the knowledge of how much energy (and money) can actually be saved by these practices.

Since tastes and preferences are often a sensitive — and widely varying — subject, care must be exercised in discussing conservation via taste changes. How the energy user responds to the level of (or trend in) energy prices depends on both the possibilities for factor substitution and the consumer's own long-run marginal preference for the amenity that energy makes available. Whether the consumer conserves (and saves money) by insulating his house at a given price depends both on whether he has access to capital and information and whether he is motivated to do so. If in the long run he might come to prefer different indoor climates depends also on price, information, and motivation, but these two conservation options may have different price sensitivities. Clearly our knowledge of future demands depends on knowing how price and other factors influence both the opportunities for technical fixes and the possibilities for changes in behavior and preferences. We should be wary of projections for future "needs" based only on historical data that do not reflect these possibilities.

Similarly, we must exercise caution when projecting energy needs on the basis of highly aggregated statistics, since some of the goods and services produced with energy may be demanded in lower quantities than otherwise if rising energy costs, though mitigated by technical substitutions in the production processes, are nevertheless felt in those goods and services. Such lifestyle issues are a difficult subject, as difficult fixes as forecasting consumer preferences. That many technical fixes exist suggest that a given lifestyle, or final consumption market basket can be satisfied for widely varying amounts of energy with other resources, amounts which depend in part on the relative prices for energy forms and the state of the art of energy use technology. But changes in lifestyle can still influence energy consumption levels and patterns, as the travel example above indicates. Thus, we cannot ignore lifestyle issues.

Lifestyle: The Mix of Goods and Services

We have suggested that changes in the mix of non energy goods and services demanded can have impacts on total energy use. In the long run this effect can have significant influence on overall energy demands. This is because the total energy cost of providing goods and services varies greatly over the components of bundle of items consumed today (see Ref. 2 for a discussion with many representative energy intensities). This does not mean that the bundle can assume any intrinsic structure energy intensity, though, because goods and services are often interdependent; not any arbitrary combination will be produced in equilibrium, nor would any arbitrary combination produce maximum consumer satisfaction. Furthermore, certain key energy using activities, such as personal or commercial passenger transportation, are tied in various ways (relatively unexplored heretofore) to the production and use of goods and services; fly fishing is extremely time intensive, and the production of the equipment is labor intensive, but the fishing may be several hours (and gallons) by car away from home. Certainly, too, the changes in what people buy and do may have important implications for energy use, implications that transcend concerns about

energy, whose costs are buried deep in the total cost of what is bought or done. While we can estimate the energy impacts of any group of decisions, our ability to predict in detail the composition overall mix of activities is still limited. Even the often cited trend from manufacturing towards services can be misread, since services include homes, hotels, and gasoline, while goods include the above mentioned fishing gear, hand-held calculators, and citizens' band radios, all with energy intensities (including use) considerably below the national average. Thus we need to know <u>which</u> goods, and <u>which</u> services, before prognosticating about energy can be secure. Finally, we should reemphasize that only a few non-energy goods and services are energy intensive (measured in Btu consumed/dollar of final demand). This means that changes in energy prices will only have a small effect on the prices of most of the consumption decisions involving these activities.* Energy is still the tail; the economy the dog, and it seems reasonable to assume that other economic or social forces might act long before energy costs are felt to change considerably the mix of goods and services consumed.

Lowered Level of National Output

Other things equal, curtailed output of goods and services would obviously lead to lessened need for energy; and greatly curtailed output could drastically reduce energy consumption. We are not here debating the merits of dampened rates of economic growth or the more extreme case of a steady-state society. Both may conceivably be

*Airline travel, chemical preparations, fertilizers, containers and packaging are some important exceptions, for which energy costs are significant (see Ref. 2 and references therein).

laudable objectives in themselves for a variety of reasons, of which curtailed energy consumption is only one. (Environmental preservation and moderation of other kinds of resource depletion are additional possible reasons.) Because of these wider ramifications of the growth controversy, we deem it prudent to confine energy conservation to a situation of reducing energy use without encroaching on national output, as conventionally measured.

The term "as conventionally measured" calls for a passing reference of its own. To disallow curtailed physical output of goods and services as a route towards energy conservation seems to imply that a diminution of output necessarily spells a corresponding reduction in society's well being. Why else preclude dampened economic activity from contributing to energy conservation? The answer lies not in any faith that a growing GNP — the conventional yardstick of nationwide, market-oriented economic activity — guarantees enhanced human welfare and perceived happiness; or that a shrinking GNP need signify an erosion of such welfare. Rather, the problem arises from the fact that GNP and its underlying components do represent an objective reckoning of expressed market preferences, whereas any substitute standard of the social product would almost certainly involve the imposition of intensely controversial and debatable value judgments.

It would, for example, constitute a perfectly legitimate philosophical proposition that society's welfare be denominated, not by reference to recorded GNP, but in terms of some minimal physical or physiological attributes — such as dietary intake, shelter, heating,

illumination, health, and so on. And for purposes of exploring the resource implications or severely constrained growth — no matter how occasioned — such speculations can be highly instructive. However, broadening the scope of energy conservation — which, as we shall see, involves a multiplicity of cases anyway — to embrace such hypothetical circumstances, would greatly muddy up what it is we are trying to clarify.

V. OTHER PERSPECTIVES ON ENERGY USE AND CONSERVATION

So far we have considered energy conservation as a problem at the micro-level, discussing how people — and systems — might use energy in different ways. It is instructive, however, to extend our discussion by focusing on the macro-history of energy use in our own country.

The U.S. Historical Record as an Illustration (12)

The combined way in which industry and households act within these crosscurrents of technological change, economic incentives, and societal preferences helps shape the countrywide character and aggregate of the demand for fuels and power. It is worth reflecting on this somewhat more abstract level, for there is currently much preoccupation with the energy implications of levels and growth of nationwide economic activity — both on a national as well as a comparative international context.

Indeed, the long-term record of energy consumption relative to GNP in the United States bears witness to the presence of such underlying structural and technological forces as we have mentioned. For example, the steeper rise of energy consumption than of GNP in the closing decades of the 19th century and in the early part of the 20th almost certainly reflects the disproportionately fast growth of manufacturing in the economy — a sector requiring far higher energy inputs per unit of activity than the agricultural component, which had dominated the economy earlier..

Conversely, among the forces making for relatively slower growth in energy consumption than in GNP for much of the 50-year period following World War I was the rapid rise of electrification, which greatly enhanced

efficiency of factory operations and the rising productivity of the American worker, in spite of the fact that the generation of a kwh of electricity required at least four kwh of heat.

This disadvantage was itself moderated in a very important respect, however, by steady improvements in electric generating efficiency. Another important instance of improved energy conversion was the replacement of steam locomotives by more efficient diesel engines, during a time when rail transport was still an important user of energy and deliverer of both passenger and freight services, the latter of which is still important today. Finally U.S. manufacturing fell in energy intensity, especially since World War II (13). This occurred because technical fixes allowed each energy using process to become less energy intensive (in spite of falling energy prices); fuel switches allowed more effective combustion of gas or oil (vs coal); and some changes in output mix advanced production of less energy intensive products more quickly than more energy-intensive raw materials, i.e., drugs instead of raw chemicals. Thus for the period 1920-1960, U.S. energy consumption, on the average, grew at only 2/3 the annual rate of real GNP growth. This is quite remarkable since other uses of energy were expanding more rapidly than GNP, uses that register as final demand, such as household uses and personal automobile travel. That is, lifestyle changes had been taking place, changes that have influenced the energy requirements of economic activities as measured by the ratio of energy use/Gross National Product. Consumers came to purchase more energy per capita for direct uses, but decreases in the price of energy allowed total expenditures to remain at a cost share. One can hardly help but note that the decreasing real prices for fuels and electricity (and automobiles) probably played an important role in allowing Americans to move farther from each other, occupy larger spaces, and travel more than most other industrialized peoples.

Structural changes in the economy, reflected in changes of lifestyles and in the mix of personal consumption activities, can, as in this example, mask the changes in energy intensity that are most readily identified with energy conservation. Conversely, however, energy conservation does not mean that the trend (if any) towards larger homes will or should stop solely because of energy considerations — rather conservation simply means that the total resource cost of heating any home, in particular larger homes, will be less than if conservation is not practiced. In this sense <u>conservation</u> per se is <u>not</u> a barrier to greater affluence and/or increased incomes, but simply another means to provide for more goods and services for a given income.

When all the different energy uses and intensities are added together and compared with changes in the Gross National Product, the two quantities seem to be well correlated historically, GNP growing slightly faster. This correlation has lead to an intense debate, in which it may even be asserted that conservation will not occur <u>because</u> that would change the energy/GNP ratio faster than history permits.* We deem it worthwhile to review some aspects of this remarkable ratio.

*See, for example, H. Linden (Ref. 14). It should be noted, however, that Linden and co-workers derive a correlation that includes the effects of aggregate energy price levels.

The Energy-GNP Ratio

There is no question that the Energy-GNP ratio has been the subject of exhaustive investigation and debate.[14-18] Some studies rely principally, or solely on projection of this ratio in order to arrive at future energy demands. We suggest, however, that the aggregate nature of both the numerator and denominator in the ratio warn us to treat this number with extreme caution. Superficially, the ratio is a rough indicator of the relationship between energy use and standard of living, in so far as GNP measures standard of living. Certainly the difficulties in evaluating comparing GNP from a single country over time or among countries are well known. But more important, the use of GNP and energy totals obscures often dramatic differences in economic and demographic structures that influence energy use — and intensity.

For example, energy use totals do not differentiate between electricity and individual kinds of fuels, each of which have characteristic thermodynamic and use of properties as well as different prices. The influence of climate is seen in the demand for fuel and for space conditioning but not reflected directly in the GNP, as is the geography and density of countries and regions. The energy embodied in products that make up the bill of import or export goods should also be considered.

More important, though, the detailed make up of the GNP, or final demand vector, shares with intensity of energy use in determining how much energy is required to support a certain GNP. Thus countries where a relatively higher portion of energy, in whatever form is delivered to final demand would tend to have a higher energy/GNP ratio than countries whose intermediate demands were similarly structured but whose demand for energy for heating and transportation were significantly lower because homes were insulated or autos were smaller (or driven less). This is because energy delivered directly to final demand "produces" less GNP directly than energy used in combination with other resources to produce goods and services that make up the GNP.* Even the relative shares of manufacturing and services can have confusing impacts on the energy/GNP ratio. While it is widely held that services require less energy per unit of GNP than manufacturing, services are coupled to energy use via transportation and heating and cooling of buildings where services are made available. How much energy is "required" to make a given service available depends on how far the purchaser must travel, and how the building involved is designed and run. Thus we can warn that there are few firm rules that apply to understanding the relationship between energy and GNP — the most important use of energy and economic activities must be considered separately in detail before any great conclusions be drawn about "efficiency" of energy use.

Even at the micro-level the confusion continues. In Sweden,(4) for example, the 5 energy intensive industries (Paper, Metals, Chemicals, Refining, Stone/Glass/Clay) together require more Btu/$ of value added than those in the U.S. Separately, however, only the paper industry is more energy intensive (by this measure) in Sweden than in the U.S. Because the paper industry uses nearly half of all the energy among

*Or, energy purchases by final consumers are the most "energy intensive" purchases they make.

these sectors, its intrinsic properties dominate the aggregate totals. However, upon closer examination it is found that a ton of paper, or pulp, is actually produced on less energy in Sweden than in the U.S. But more of the value added in Swedish industry is concentrated in these raw end materials ends, while in the U.S. a larger fraction appears under such items as greeting cards and stationary. (Sweden produces four times more paper/pulp than the U.S.) Thus Sweden's paper industry is intrinsically more energy intensive but at the same time more energy efficient, product for product, than that of the U.S! Greater use of cogeneration and greater efforts to recuperate process heat are the major reasons why paper production requires less energy in Sweden than in the U.S. Higher prices for fuels in Sweden, relative to the U.S. may be the most important factor motivating this "conservation" but availability of the forest as a renewable resource means that pulp production in Sweden is an important source of income. Is Sweden an inefficient user of energy because of the large size of the pulp and paper industry or the larger ratio of E/G in this sector?* Hardly, but only a closer examination of the components of energy use and economic activity, which reveals the difference in energy intensity in single countries or among groups of countries, reveals the clear patterns of energy use and efficiency.

Indeed one recurrent theme of this essay has been that energy is but one of many resources that are combined to produce goods and services.

*B. Commoner, The Poverty of Power, uses the energy/$ ratio extensively to argue that products are "efficient" or "inefficient" depending on how much energy they require in production.(19)

Single ratios such as energy/GNP or energy/worker have become popular in discussions of energy needs, especially in predicting the future. These ratios, however, omit explicit consideration of structure on the one hand, and substitution of resources on the other.* We strongly emphasize that most reliable information about energy use, needs, and conservation comes only from a detailed examination of the uses and factors that influence the uses of energy with other resources.

*See Berndt and Wood,[20] or Long and Schipper,[21] wherein 1-factor energy models are critiqued and substitution is discussed at great length.

VI. CONCLUDING REMARKS

Energy conservation reflects the response of energy users to factors dominated by, though not necessarily limited to, prices and scarcity. Other inter-connected issues include national security, environmental and social impacts. The economies of substitution of non-energy resources for energy are becoming better understood, but our knowledge about the speed of change in behavior or shifts in the mix of goods and services as a function of energy prices and policies is far from perfect. In any case, we deem it important to delineate some of the principal forces at work in the course of the conservation response, noting however, that the mere existence of these possibilities raises as well, questions of implementation and feasibility. The social equity implications of higher energy prices illustrate one such issue.

From a physical standpoint, no unique amount of energy is required to perform tasks in the economy today; we are far from thermodynamic limits. Our choices of how to use energy — and how much we "need" — depend in large part on how costs of energy and its substitutes interact with a technology, lifestyle preferences, public policies, and institutional barriers to changes in energy-use patterns that could result in conservation. Both the historical record of U.S. energy use and foreign experience show considerable flexibility in energy needs — seen either from a technical (substitution) viewpoint or a behavioral/lifestyle viewpoint. Conservation is not simply an issue of waste versus non-waste, the boundary line between these two extremes being defined both by economics and by tastes and preferences. In this light, however, it is possible that growing worldwide energy consumption is raising consciousness among people in industrial nations over the moral implications of high — or low — energy consumption levels. Finally, we recall that energy intensity alone is not a criterion for waste or efficiency; other economic and social factors must also be considered. The measurement of "energy conservation" does not stem from simply comparing aggregate levels of energy use or even energy use per capita or per dollar as between various years or countries, but is best made in terms of discrete components of economic activity or a process-by-process or task-by-task basis.

While our economic definitions of energy conservation implies that economic considerations may be the most important criteria for deciding on the desirability of energy conservation strategies, we recognize the collateral importance of such difficult questions as waste, lifestyle, and indeed, growth itself in connection with energy conservation. But from the standpoint of clarity, these issues are best taken up on their own operating points might usefully be evaluated in order to predict how much energy could be conserved relative to prevailing practices.

If our discussion appears to have imposed narrower bounds on the scope of energy conservation than some persons would prefer, these last policy-relevant considerations nonetheless point to meaningful payoffs to energy users and to society from soundly conceived conservation approaches. Perhaps the most pressing need for research today is to identify the payoffs, both in physical/economic terms and in social terms, taking due note of the direct and indirect costs of different patterns of energy use. We suspect that energy conservation offers much in economic (and other) terms. How much can be offered will play a great role in future demands for energy resources.

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LIST OF FIGURES

Fig. 1. Schematic of energy conservation.

Fig. 2. Substitution of capital for energy: The Refrigerator. Vertical axis gives daily consumption in MMJoules; horizontal axis the change in first cost. The cluster of numbers by each point represents the collection options evaluated (from Hirst).[7]

Fig. 3. Percentage savings in heating energy use as a function of thermostat setback, for several regions and temperatures. While the percentage changes vary greatly, the absolute savings from region to region are nearly the same (from Pilati).[8]

Fig. 4. Capital cost of additive natural gas conservation options vs. amount saved per year, for an uninsulated house commonly found in California. The curve was derived from Rosenfeld et al.[10] Note that the automated night setback, with a low capital cost ($) does involve behavioral changes insofar as indoor climate is concerned. The other capital costs are shower head restrictors ($3.00); water heating insulation ($21.00); attic insulation ($); wall insulation ($); and storm windows ($).

FIGURE 1

Reduction in Demand for Scarce Energy Resources

Curtailment

Heroic means in face of emergency. Sometimes counterintuitive
- inverted rates
- gasless Sundays
- rationing
- allocation
- restricted commercial hours

Efficiency

concept of market and welfare economics, technical innovation and implementation, stewardship

Fuel Switching

- natural gas to syngas
- natural gas to coal-fired electricity
- gas, oil to coal

Improved Efficiency of End Use

Substitution of other resources for energy

Improvements in technology through innovation and R&D

Improvements in supply/delivery systems

Systems approach: matching supply and demand

Behavioral Changes Directly Effecting Energy

Smaller cars

Lower thermostats

Fewer miles driven

Altered Patterns of Non-Energy Consumption and Life Style

Mass transit

Final demand mix

Urban planning, changes in land use

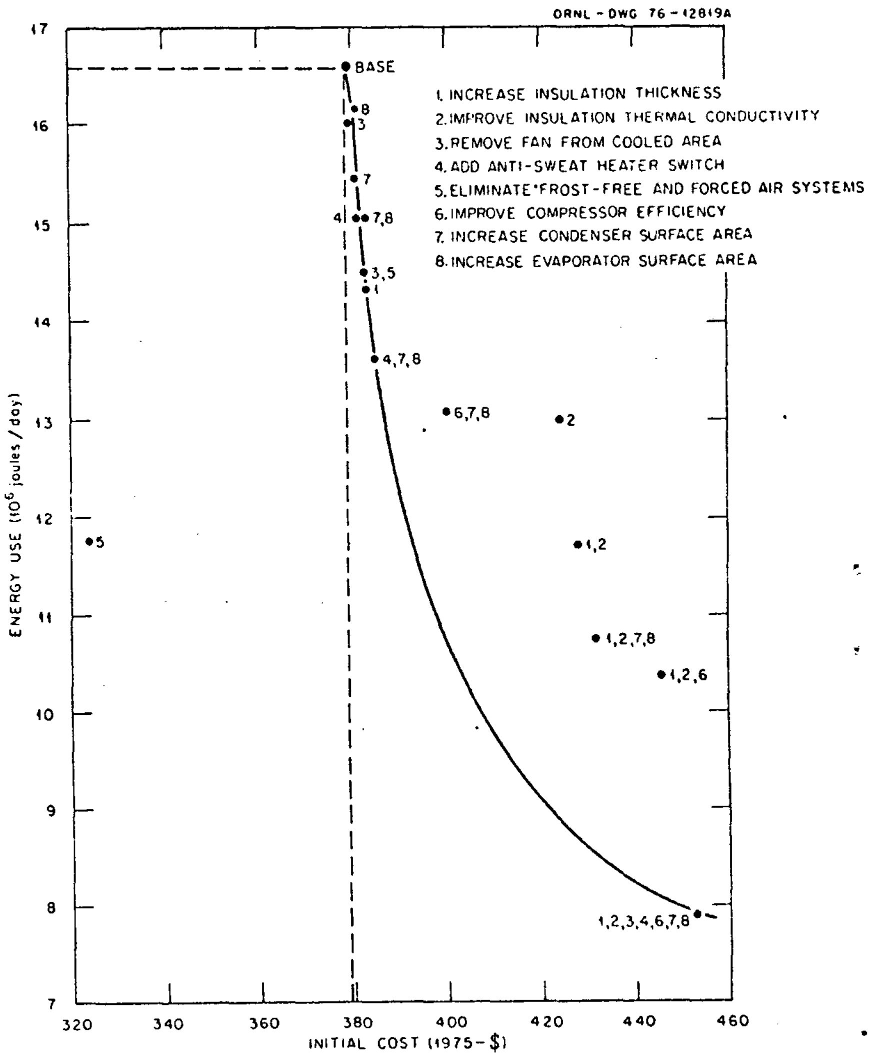

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Figure 2. Energy use versus retail price for various design changes for a 0.45 m^3 (16 ft^3) top-freezer refrigerator.

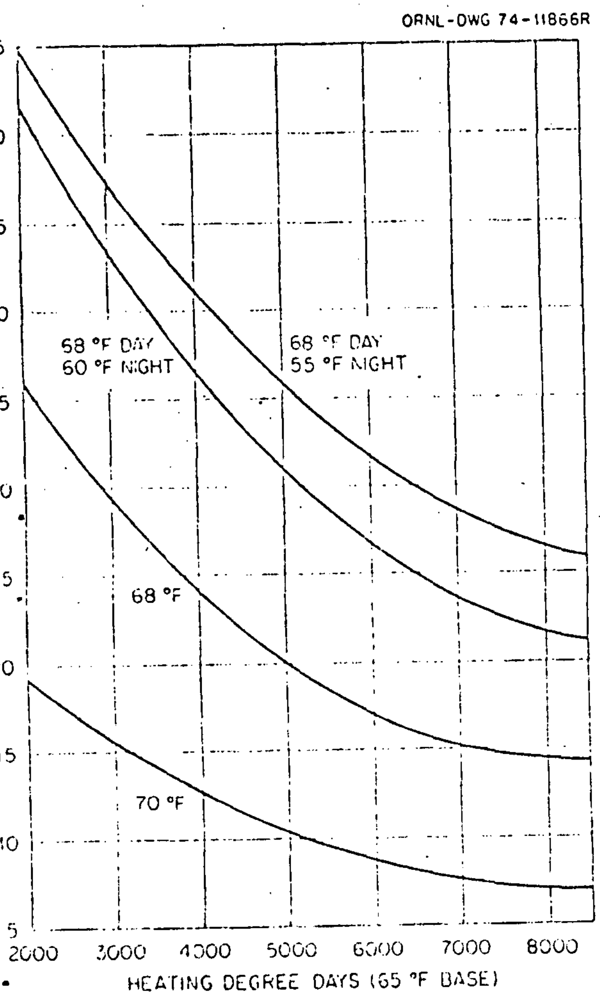

Figure 3. Predicted energy savings for several thermostat settings (72°F is the reference setting and night setback is from 10 p.m. to 6 a.m.).

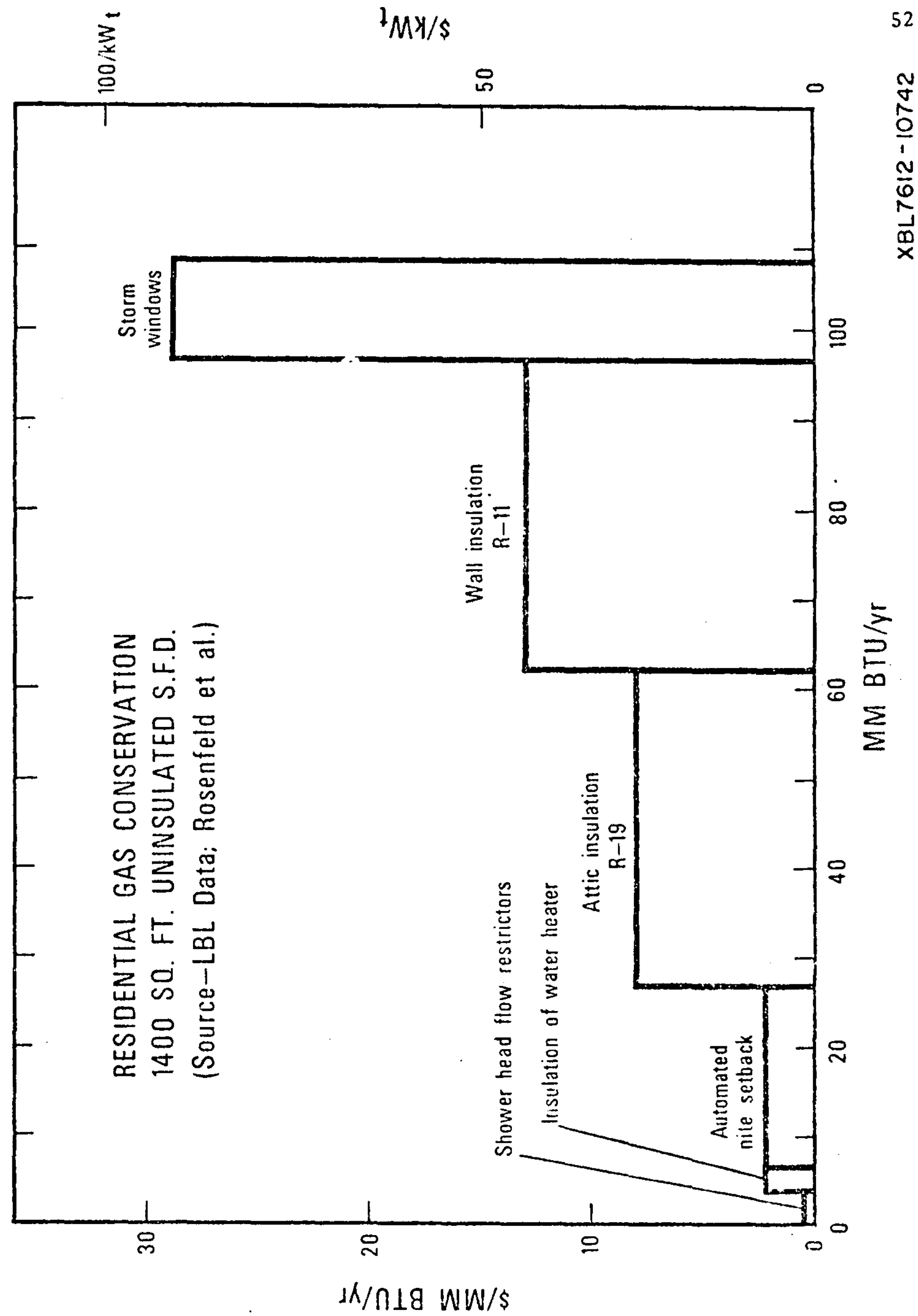

Figure 4

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