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BASIC RESEARCH NEEDS IN ENERGY CONSERVATION

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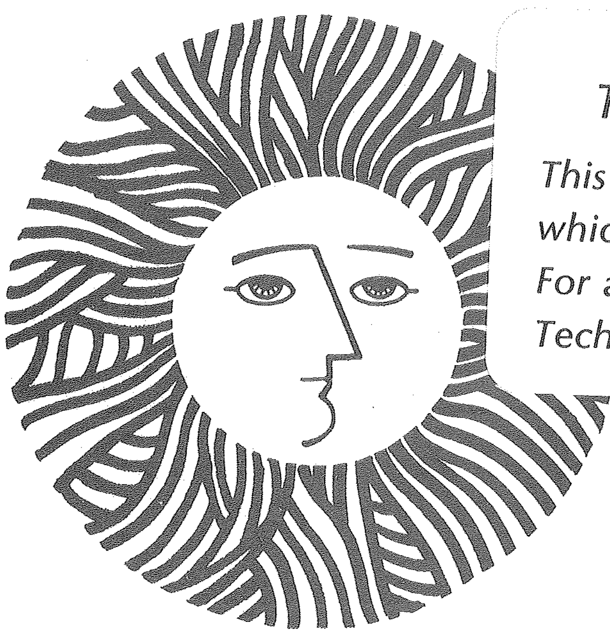

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BASIC RESEARCH NEEDS

IN

ENERGY CONSERVATION

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I. WHAT IS ENERGY CONSERVATION?

While energy conservation has come to have many political, social, and environmental connotations, the most important reason to find ways to use energy more efficiently is that, on the average, it now costs considerably less to save a unit of energy than to produce one from new supply (1-3). To the extent that presently non-quantified social and environmental costs (externalities) are also included in the accounting, the impetus to use energy efficiently would be even greater. Energy conservation is thus the economically efficient societal response to the rising cost of energy relative to other resources. The overall goal of conservation is to enable society to accommodate future demands for goods and services with minimum total costs, including energy and resources.

Under the general rubric of energy conservation we include the following societal responses:

1. Responses by which existing energy-using equipment and processes are gradually replaced with more-energy-efficient ones. To bring about this replacement, other resources of lower cost are substituted for energy. The substitites include capital, labor, materials, information and, above all, human ingenuity. Development of new equipment and processes requires time -- in some instances only a few years, in others decades or more -- and is subject as well to a variety of non-economic constraints. This class of responses does not involve change either in short-term consumer behavior or in the long-term level or mix of consumer amenities and activities (i.e., no life-style change).
2. Responses that involve short-term changes in consumer behavior towards important energy-intensive activities. These changes are induced primarily by higher energy prices. The consumer continues to use existing capital equipment in the short term, but reduces the amount of use, in the judgement that this is less costly than investment in new, more efficient equipment. Examples are: reduced use of hot water, less driving, lower settings of

thermostats in winter and higher settings in summer.

3. Responses that involve long-term structural changes in the economy that produce a less-energy-intensive mix of consumer activities. Such changes may either come about as a result of energy conservation or themselves be a cause of energy conservation. They would be brought about, in the first case, by relative energy price increases and government regulations; in the second case, by changing social values affecting consumers' tastes and preferences in consumption, location, and occupation (4).

The combined impact of these responses to higher prices and government policy will be a lower growth rate of energy use than would otherwise be the case. But, how much lower? An assessment of a wide range of energy futures made by the National Academy of Sciences CONAES study indicates that a serious national energy conservation program, implemented gradually and consistently over the next two to three decades, could reduce energy consumption by 2010 (in relation to gross national product) to about 60% of what it would be in a "business as usual" future (1-3). For example, in the case where 3% average annual GNP growth is assumed, total U.S. energy use in 2010 was projected to be around 115 quads for a high-conservation scenario, in contrast with around 190 quads for a "business as usual" demand scenario for 2010. This corresponds to a potential "saving" of 75 quads, which is equivalent to the total present U.S. energy consumption.

The energy supply analyses done by CONAES show a similar differential: in a "business-as-usual" future, the U.S. domestic energy supply system will probably produce only about 75 quads* in 2010, whereas a national program committed to enhanced supply production could deliver around 150 quads (5).

Thus, the potential overall impact of a vigorous energy conservation program is similar to that of a vigorous energy supply program. Since neither energy supply nor energy conservation goals are likely to be fully met, the nation needs both elements as partners in its energy program. Indeed, energy conservation should be considered as the equivalent

*primary resource input equivalent

of an energy supply system: every quad saved by use of a more efficient technology or practice is equivalent to a quad that does not have to be supplied by an existing or new supply technology. And conservation has the advantage that it generally involves lower environmental costs than supply systems and renders the economy more resilient to supply interruptions.

II. GOVERNMENT RESEARCH IN ENERGY CONSERVATION

In this section, we develop these themes:

1. The role of research in energy conservation.
2. The role of governmemt in conservation research.
3. The role of basic research in conservation.

Why energy conservation research? If we accept the strictly economic definition of energy conservation as a rational response to higher costs of energy, should not the market place alone be able to handle the inevitable adjustments? In a "perfect" economic market, energy prices would reflect the true total costs to society of supplying and using energy. Consumers would have perfect information about those costs, and would spontaneously adjust the nature and magnitude of their purchases to the lowest total cost for each amenity desired. The commercial sector would include energy costs as one of the relevant factors of production, and would make appropriate investments in R&D to bring about cost-effective increases in efficiency of energy converting-and-using equipment and processes. The time involved in bringing about these adjustments would be socially optimum.

In fact, none of these situations obtains. The energy market is far from ideal; its natural workings are inconsistent with U.S. national security; and the economic adjustments take too long. Domestic and international political forces have produced an energy market with a price structure very different from what it would be if it had been determined entirely by economics. Although the price structure is changing, future trends in regulation and in foreign supplier policies are uncertain. Social and environmental costs are not fully included in energy prices as they would be in an ideal market, and there is great uncertainty as to how they can be evaluated and internalized. Consumers generally do not have adequate information on energy costs and cost trends, and do not know how to relate these to decisions on purchases. Balancing increasing domestic demand in the face of diminishing domestic supply by ever-growing dependence on imports may be workable from a market standpoint, (at least in the short term), but it is not consistent with U.S. national security, both because the extent of imports contributes directly to inflation, and because most of the imports originate from politically unstable regions of the world. Therefore, acceleration of energy conservation has an important national security value. Finally, experience has demonstrated that the energy-conservation response of private-sector institutions is excessively slow because of the many uncertainties of the energy market. This inertia is a matter for public concern because of the very long lead times required to develop and deploy long-term energy supply systems and because of the formidable problems faced by the available short-term supply alternatives to oil and gas.

Research in energy conservation is necessary to help mitigate all of these market shortcomings, to catalyze the taking hold of conservation. Technical research can accelerate the introduction of innovative ideas and technological options as substitutes for energy use. Environmental research can help ensure that proposed conservation measures adequately protect public health and safety, and can assess the level of environmental benignity of conservation solutions in comparison with equivalent energy supply alternatives. Social research can provide the framework for developing institutional mechanisms to accelerate the implementation of energy conservation practices and technologies.

Energy conservation research can thus contribute in essential ways to slowing the growth in energy consumption, and providing valuable time needed for solving the many problems accompanying the development of long-term sustainable energy systems. An important specific benefit of conservation research is to reduce uncertainties in our estimates of future energy demand, or, stated another way, to increase our confidence in assessments of the implications for future energy prices and energy demand of today's trends and decisions. To the extent that these uncertainties can be reduced, planning for the development and allocation of alternative energy supply resources and technologies can be done in a more economically efficient way.

Why government research? As the cost of energy rises, more and more investments in increasing the productivity of energy use will become profitable. Where there is a clear potential for nearterm payback from investments in improved efficiency of products or processes, private industry can usually be expected to sponsor the requisite applied research, as well as subsequent development and commercialization efforts. This is especially true where unique skills or manufacturing facilities are possessed by particular firms. Normally, government should not compete with industry in doing short-term, low-risk applied research. The principal role of government research should be to keep informed on the state of the art. If it appears that a stimulus is needed for industry to move as quickly as is warranted by societal need or commercial opportunity, government should sponsor the needed research, in collaboration with industry if possible. Examples where DOE laboratories are playing a key role in applied research, working collaboratively with industry, are in the development of heat pumps and energy-efficient windows and lighting.

A class of research problems intermediate in character between short-range applied research and fundamental research pertains to problems which, although related to specific technological goals, either do not show sufficiently high probability of early economic return to industry or have an inherent time horizon beyond that normally considered by industry. The responsibility for such applied research usually falls to government; nonetheless, the work is best carried out in close coordination with industry in order to facilitate the transfer of results when the work reaches a stage appropriate for industrial interest. Activities of this kind constitute the major missions of the various DOE technology divisions; in conservation, they are conducted under the auspices of the Assistant Secretary for Conservation and Solar Applications.

Why basic research? Fundamental long-term research in many sciences has traditionally been supported by government simply because it is in the nations's interest to do basic science and such studies are beyond the reach of most private capital. Opportunities abound in energy conservation for rich rewards in the long term, yet basic conservation research has had a slow start because of the widespread, yet erroneous, impression that most conservation goals are short range. In fact, a dedicated and continuously supported public program of basic research in energy conservation could have a major positive impact on the nation's long term energy future by facilitating the emergence of a high-efficiency, low-energy use society which will be much easier to supply from the high-cost energy technologies of the future than would be a society extrapolated from today's low-efficiency, high energy use.

J. H. Gibbons has stated well the ultimate challenge to energy conservation: "To what extent can man substitute ingenuity for resource consumption?" (6). Basic research in energy conservation is largely addressed to this question. The following are major goals:

1. Obtain a sufficient foundation of physical, chemical, and biological knowledge to make possible the economic development of future energy-efficient conversion and end-use technologies. Learn how to accomplish tasks that require energy, in entirely new ways rather than by incremental improvements to existing ways. Most of today's uses of energy are far from the limits of efficiency imposed by physical laws; basic research should aim to "constantly roll back the limit to efficiency that is compatible with a given energy price."(6)
2. Gain a greater fundamental understanding of how energy is used in this and other societies, in order to reduce uncertainty in assessments of future energy demand and to facilitate the transition to an energy-efficient society. Greater knowledge is needed of how energy use responds to price signals from the market and non-economic signals from government and social groups, and of how these responses affect social equity, civil freedoms, environment and health, national security, and the levels and time-scales of energy-supply development.

The second goal bears some elaboration. Traditionally, energy research and policy has made little use of the social sciences and, conversely, little social science research has been done on problems related to energy. It is clear, however, that there are fundamental unknowns about the human dimensions of the energy problem: impacts of energy use on people, and impacts of how people live on energy use.

Past research efforts have been too few and usually done in an ad-hoc fashion in support of or opposition to particular policies or technologies. Such investigations should be elevated to the level of basic research into the interaction of energy and society.

The following sections are devoted to a discussion of areas in energy conservation where basic research is needed. This presentation makes no pretense to be exhaustive nor even completely uniform; some topics are described in much more detail than others. What it does do is provide important examples in each identified category of research need. It was beyond the scope of this initial effort to review or provide commentary on ongoing programs of the Office of Basic Energy Sciences, relevant to energy conservation, or to set priorities for the support of further research. These tasks should be done.

III. RESEARCH NEEDS: PHYSICAL AND ENVIRONMENTAL SCIENCES

The expected increasing price of energy in the coming decades will in principle provide many economic opportunities for increasing the efficiency of energy use. Great uncertainty exists throughout the economy, however, in the levels of efficiency that are technically achievable at given energy prices. It is extremely important that these uncertainties be reduced by research, so that short-term energy supply production targets can be set at realistic levels, and better assessments made of our probable long-term energy requirements.

The major goals of the basic research described in this section are increasing the technical efficiency and environmental benignity of energy production and use. These long-range studies would explore the fundamental causes of energy inefficiency and the achievable limits to energy efficiency; the complex coupling between energy efficiency and pollutant formation; the matching of energy quality and technological scale with characteristics and requirements of energy use; the substitution of new ideas for existing technologies. The research needs run the gamut of disciplines and potential applications.

A. Industrial Processes

Research is needed in a number of areas, some of major scope. Optimal changes to improve industrial productivity are often multipurpose, so certain areas not specifically focused on energy may well have the greatest impact on energy. Many long-existing areas of study have been relatively neglected in modern research. For example, fundamental research on basic materials processing (such as paper and steel) and exploration of new basic materials processes are needed. Basic mechanical studies should be carried out on friction and lubrication, control of fluid flow, and (at the microscopic level) fundamentals of separation of materials by processes such as osmosis or adsorption. Heat transfer should be more deeply examined, e.g., at surfaces, in boiling, and in two-phase flow. Studies of sensors are needed, to facilitate application of automatic control systems.

The processes for coal conversion to synthetic fuels currently under development themselves consume an appreciable fraction of the energy content of the coal used (7). In the process industries generally, up to 50% of energy consumption has been estimated to result from inadequate process control (8). Study of process efficiency is therefore important from an energy conservation standpoint. In particular, studies are needed of catalytic mechanisms relating to less severe and more selective reaction conditions for coal liquefaction and gasification. Less severe conditions mean lower temperatures and more energy-efficient processing. For in-situ conversion processes, studies should be made of fluid flow in porous media of low void fraction. Control and dynamic interactions of complex, highly integrated process systems should be studied, in order to devise ways of achieving favorable process dynamic interactions in such systems. Also, more extensive use of heat exchange and other energy-integration methods in processes can be facilitated by more effective control.

For direct coal use to be able to develop in an economically and environmentally acceptable manner, flue-gas desulfurization processes must be improved. Many processes have been proposed but assessment, utilization and improvement of most is held back by lack of knowledge of fundamental chemistry or mass transport mechanisms (9). In the chemical and food-processing industries, at least 80% of energy consumption takes place in separation processes. There is need for energy-efficient alternatives to presently used vaporization methods (distillation, evaporation, drying), which are particularly energy intensive yet widely used because of their simplicity (10,11). Efficiencies of material contacting devices need to be better understood and improved. In particular, gas-to-gas heat exchangers are very inefficient. Vapor-liquid contacting devices are poorly understood and consequently often over-designed and energy inefficient (8,10).

Several percent of the total U.S. energy consumption is attributable to electrochemical processes, offering a major opportunity for energy conservation by efficiency improvements. These processes are used for preparation of metals and chemicals, and for the storage of energy. Electrochemical processes have the potential for considerably higher energy efficiency, but this potential has not been achieved in spite of the long history of economically significant industrial applications. A major reason for this is the complex nature of transport phenomena in ionic media as they relate to the charge transfer processes at electrode surfaces. Although there have been rigorous methods introduced recently in the analysis of the processes, further research is required to improve their efficiency. Electrode geometry, surface potential, boundary-layer control, and non-aqueous ionizing media should be investigated, and corrosion-resistant materials developed for use in electrochemical cells. This research could have major impacts on the efficiency with which important industrial electrolytic processes can be carried out and in the development of very efficient batteries for energy storage purposes.

B. Combustion Systems

In order to develop and evaluate conservation strategies involving fossil-fueled combustion systems, both their costs and their environmental impacts should be considered. Before the recent sensitivity to environmental concerns, combustion systems were reasonably well optimized for minimum fuel and capital costs. Today, in the face of escalating fuel costs, this optimization must accomplish simultaneously higher fuel efficiency and increased control of combustion-generated pollutants. Nitrogen and sulfur compounds, particulates in various size ranges and unburned fuel must all be controlled ultimately, and further regulations may be expected for presently uncontrolled pollutants. This problem involves complex and poorly understood chemical and fluid mechanical phenomena. The special demands on combustion-system design posed by this complexity cannot be addressed by standard engineering methods, but only through a deeper understanding of the basic chemistry and mechanisms of combustion.

The example of the diesel engine illustrates the problem. The diesel is one of the most efficient internal combustion engines and also meets present emission standards for mandated pollutants -- CO, HC, and NO_x. However, under normal operating conditions diesels produce carbonaceous soot particles with an emission rate approximately 30 times that of equivalent internal combustion spark engines (12). Thus there is uncertainty about the desirability of increasing the diesel mix in mobile traffic, even though such a policy would be reasonable from conservation considerations alone. Further research is essential to characterize the particle emissions of diesel engines as a function of combustion parameters in well-controlled laboratory conditions, and to work out strategies for mitigating these effects. For the characterization of particle emissions, combustion nuclei and gases, in-situ-on-line monitors need to be developed and a wide range of analytical techniques brought to bear on the problem.

Another focus of combustion research should be on coal, which is likely to become increasingly utilized. Better understanding of the chemical and physical phenomena involved in coal combustion, gasification and liquefaction is needed, and problems of safety should be given increased attention. In particular, research is needed on the chemistry of coal combustion reactions, including the rates and mechanisms of reactions leading to release of heat and generation of pollutants. Both gas-phase and surface reactions need study. The coupling of combustion heat release and pollutant chemistry to turbulent fluid mechanisms should be investigated. Studies of flammability, flame spread, and toxic-gas generation should be included. To facilitate identification of chemical species in the investigations of high-temperature kinetics and turbulent fluid mechanics, a variety of new diagnostic instrumentation is required.

C. Energy Storage, Conversion, and Transmission

As the prices of fossil fuels continue to rise, advanced energy conversion processes designed to conserve fuel and to use the thermal values from waste streams will become economic. The three main paths to high thermal efficiency in advanced energy conversion are:

1. higher topping-cycle temperatures;
2. development of combined cycles using several different cycles, each operating at its best temperature range;
3. development of highly efficient fuel cells.

An example of the first and second paths is combined-cycle power plants using gas-turbine and stream-turbine components. An efficient magneto-hydro-dynamic (MHD) power plant will also be a combined-cycle plant. An example of the third path is fuel-cell development for megawatt-size efficient power plants. Many important basic research problems are connected with these developments, including the development of materials of appropriate properties and costs, and the study of environmental impacts associated with obtaining and using these new systems.

In fact, materials problems are of central importance in almost all energy technologies. Materials that would permit conventional fossil or nuclear fueled boilers to operate at even slightly higher temperatures -- hence efficiencies -- could have dramatic economic consequences; inner wall materials problems may be among the most serious to be encountered in progress central in the development of solar energy technologies. Costs and reliability are among the major issues. There are many areas for important basic research in metals, ceramics, refractory and resistant materials, corrosion, high-temperature performance and in thin films of particular importance in solar work. Basic solid-state research, including studies of both crystalline and amorphous semi-conductors, is very important for the development of advanced energy conversion systems.

Research should aim at developing conversion processes that best match future fuel supplies, for example, the substitution of electrochemical or photochemical processes for current thermal chemical processes, so that more appropriate and efficient use can be made of electricity and solar energy than simply as heat sources.

Progress in the technology and economics of long-distance transmission of electric power may alleviate the problem of power-plant siting by increasing the distance between plant and consumer, and possibly by co-locating several plants to concentrate the safety problem and introduce economies of fuel handling or reprocessing.

The possible wide application of hydrogen as a carrier and secondary source of energy in the future requires solution of many fundamental chemical problems relating to its storage, transmission, and use. Basic electrochemical and thermochemical studies are also required to build a foundation for development of improved batteries.

One example of an important basic research area is investigation of the use of underground aquifers as a low-cost method of storing a large amount of thermal energy, to compensate for the time mismatch between periods of energy input and power demand in large energy systems (13). Early work in numerical modeling demonstrated the feasibility of the concept. Although several DOE demonstration projects are planned, important basic research is necessary to understand the physical and chemical processes involved and to study various possibilities associated with the concept. In particular, equilibrium and kinetic data are needed for geochemical reactions at higher temperatures. Physical processes that may affect storage efficiency need to be studied; these include thermal dispersion due to aquifer inhomogeneity and thermal front tilting from buoyancy flow. Studies need to be made of optimal aquifer characteristics and storage periods and cycles. Major work must be done to improve modeling capability in incorporating ground surface temperature and rainfall conditions; this is relevant to proposals for use of shallow aquifers, which have the advantage of lower cost but the disadvantage of being more affected by surface conditions.

D. Buildings

With proper building design or retrofit, it is possible to save at least half of the energy needed to heat and cool a typical building. Since the buildings sector consumes 36% of total U.S. energy consumption, the potential savings from conservation in buildings is substantial. To achieve this potential, better understanding is needed of the factors contributing to energy use, including design components (e.g., windows, envelope, insulation) and construction factors (e.g., air infiltration). The principles of energy- and optically efficient lighting are poorly known. Improved theoretical methods for modeling energy use in buildings are required as a prerequisite to the design of enforcable building performance standards.

The development of more efficient heat pumps, including designs with thermal activation for use with solar systems, is very important to increasing the energy efficiency of buildings. Better concepts for hot and cold storage systems are also needed. Research is needed to increase the energy efficiency of total communities, including studies of community heating and cooling systems.

Improvements in energy-efficiency of buildings by technical innovations in energy conservation are intimately related to the use of both active and passive solar energy concepts and designs. It is very important that research, development, and demonstration programs in energy conservation and solar energy for buildings all be closely integrated.

One example that illustrates this close connection is research into control of solar heat through windows. Existing methods include mechanical shutters, blinds, drapes, and shades, as well as non-operable devices such as reflective coatings and heat absorbing glass. The latter sacrifice operability but are easier to retrofit, having no moving parts and requiring no special hardware. However, such non-operable devices cannot take full advantage of situations where solar gains are desirable for only part of the year or where increased visible transmission would be desirable during overcast periods. A cost-effective optical shutter with a variable solar transmission ranging from transparent to opaque-reflecting would be a very desirable complement to existing mechanical sun-control options. It is estimated that the energy savings from such a device would justify an added investment cost of $10/ft^2.

Research and development of reversible optically active materials is taking place today in diverse fields, and many physical mechanisms are being explored, including photothermochromic and electrochromic materials, liquid crystals, colloidal suspensions, absorption edge shifts, solid state phase transformation, and electrolytic precipitation of metals (14). There are serious problems with most available techniques, and none that are promising can be produced at the fast rate, high volume and low cost required for widespread use, especially for retrofits. Basic research is essential in order to develop and produce a cost-effective device with the proper characteristics.

One promising basic research area is the study of photochromic light absorbing glass of the type used successfully for sunglasses. The mechanism involved is light scattering from silver particles formed by photochemical decomposition of silver halide crystallites. The presence of metal particles indicates the potential to make a device that becomes reflecting rather than absorbing, to avoid reradiation of heat to the interior. Research is necessary to understand better the scattering reflection process. Another problem is incomplete darkening in sunlight due to strong absorption at the peak activation wavelength of 0.35 microns, thus confining the effect to a thin surface layer. If a deposition method can be devised to apply a thin film of photochromic material to glass or plastic, direct transmission could be reduced and less silver halide required..

E. Transportation

Basic research in the transportation sector is needed to obtain knowledge required for development of extremely energy-efficient engines, vehicles, and transportation systems. Included should be fundamental properties of fluids that might be used in advanced engine cycles. As stated above, basic research in many aspects of the chemistry of combustion could lead to design of more efficient and less polluting engines, especially in the case of diesel engines. Engine efficiency can also be markedly improved by the design of "smart" control systems that use advanced microelectronics. Vehicle efficiency can be increased by studies of air drag at operating speeds.

One facet of the potentially great impact of telecommunications is its ability to help moderate transportation energy demand by substituting for travel and by improving the efficiency of transportation energy consumption. In regard to substitution, quantitative data are sparce and the element of causality complex (15). It cannot be ignored that previous growth periods of travel, transportation, and congestion occurred during the burgeoning of telephone and telegraph. In regard to efficiency, the potential impact is less complex, as telecommunications will be able to improve vehicle flow to optimize speed and reduce stop-and-go cycles, indirect routing, and unnecessary repositioning of empty vehicles. Much more study is needed to examine quantitatively these important potential energy-conserving ramifications of telecommunications.

F. Thermodynamics and Systems Studies

The present U.S. energy system is far from optimized in regard to matching of the type, thermodynamic quality, and unit scale of energy supply with end-use function. For example, about one-third of U.S. electricity supply is used for heating and cooling, functions that do not require energy of such high thermodynamic quality. Both economic efficiency and energy conservation would suggest that energy should be supplied only in the quality needed for the task at hand (16). Competing goals, such as convenience, often work in the opposite direction (e.g., use of electricity for residential heat) and these should be considered in any analysis. Today there does not exist a compendium of energy end-uses, analyzed according to these characteristics. Research is necessary to obtain such correlations and analyses of the energy end-use spectrum.

Basic thermodynamic theory is a subject that can contribute importantly to gaining an understanding of how well real processes can perform when they operate at real, non-zero rates. Thermodynamics research can clarify how closely maximum efficiencies can be approached, and has a great bearing on the future design of engines.

G. Environmental Impacts of Energy Conservation Strategies

Two important avenues to improving the energy efficiency of buildings have been use of more insulation and tightening of building envelopes to reduce air infiltration. These conservation measures could have significant negative impacts on human health. There is, however, little information today regarding either the level of risk involved or practical measures that could be taken to reduce that risk. Basic research is needed in both areas (17, 18).

Indoor air pollution results from emanations of chemical compounds and radiation from building materials, as well as from indoor activities such as cooking or heating with open gas flames. The level of pollutants was probably negligibly low as long as high ventilation rates were being maintained, but has become of concern since lower rates of air exchange are now being recommended or used as energy conservation measures. Research is needed as background to the development of energy efficient yet environmentally clean mechanical ventilation systems. Materials studies are needed to develop and evaluate suitable heat exchanger media in heat recovery devices that transfer both sensible and latent heat, yet impede transfer of pollutants across the heat exchanger media.

Basic research is also needed to understand the mechanisms of pollutant release from insulation materials and to develop ways to reduce such releases. Urea-formaldehyde is the most common resin used in wood products; research is needed on release of free formaldehyde (and other organics) from particleboard and plywood, and on specific additives to reduce the formaldehyde release. Other bonding techniques currently being considered by the industry (for example, nitric acid under pressure) also need to be studied in terms of chemical characteristics and potential side effects of the pollutants released from the materials employed. Studies should be conducted on emanation mechanisms of radon gas and other contaminants from various building materials (e.g., concrete and brick), as well as from soil and water. An understanding of the health risks of fiberglass insulation is also needed.

IV. RESEARCH NEEDS: SOCIAL AND ECONOMIC SCIENCES

A wide variety of basic research challenges in the social and economic sciences complement those in the physical and engineering sciences. The research agenda described in this section is aimed at increasing our fundamental knowledge of energy use in this and other energy-consuming societies, furthering our understanding of how and why people make the choices they do regarding energy, and facilitating the transition to a more energy-efficient and resource-conserving society. A central problem in energy conservation is the types and magnitudes of impacts on individuals and on society as a whole from measures to reduce the growth in energy consumption. To what extent can energy use be reduced without significant adverse impact on the well-being of individuals and society? Conversely, to what extent can energy conservation activities strengthen the economy? These and similar questions are subject to much controversy, largely because of a lack of information grounded on experience and fundamental studies. The suggested studies do not fit naturally into the present organizational structure of the Basic Energy Sciences Office of D.O.E. Because of their importance, that structure should be broadened to accommodate them.

The following are examples of some important social and economic research needs:

A. Energy Use Data Bases and Systems Studies

It is essential to collect and analyze data on actual energy consumption, highly disaggregated by individual end-uses (e.g., space heating, commercial lighting, automobile use, process heat) to determine current energy efficiency in each sector and to assess how people have actually responded to price changes and energy conservation measures over the last decade. In order to obtain maximum benefits from experience in energy conservation, it is important to obtain comparative data across different regions and countries, and to take into account relevant structural and lifestyle differences among them as factors influencing total demand. Investigation of the details of energy use in other countries can reveal much about the link between energy demand, conservation, and lifestyle (19, 20). Investigations of time series of energy use across national boundaries (21,22) can give valuable information about fundamental relationships between energy use and the economy, especially in societies where energy prices are higher or lower than in the United States, or where incomes are higher or lower than in the United States. Other countries -- or even different regions within this country -- might serve as useful "laboratories" for the exploration of consequences of changes in lifestyle, energy prices, or energy-related policies.

It is very important for energy policy makers to understand "where we stand" with regard to the impacts and consequences of past energy price levels or increases and existing conservation legislation. Research of the kind described will provide the data bases and analyses to give that information, and should be considered of the highest priority.

B. Energy Use and Evolutionary Social Trends

Some recent studies have suggested that spontaneous changes in patterns of consumption, location, and occupation among Americans may drastically reduce future growth in energy consumption (23). Up to now, such studies have been very preliminary; however, the importance of the questions they raise for future energy planning suggests that they be pursued in depth. In particular, a variety of assumptions about future life styles should be investigated, and, insofar as possible, quantitative assessments made of the impacts on energy use likely to come about from the specified assumptions.

C. Barriers to Energy Conservation

Increasing the efficiency of energy use requires not only improvements in technologies but also changes in the behavior of institutions and individuals. Often it is possible to identify factors that inhibit specific changes. Examples of such barriers include laws and codes (e.g., obsolete building codes), social norms (e.g., traditional prestige of owning a large car), mismatches between costs and benefits (e.g., master metering in apartment buildings) and poor information (e.g., lack of efficiency labeling, inability to do life-cycle costing). In these cases, strategies can be initiated for overcoming such barriers in regard to specific technologies. However, a fundamental understanding is lacking both of the problem and the proper governmental role in solving it.

Methods need to be developed for identifying and understanding the basic factors impeding the transition to higher energy efficiency. An example is the identification of individuals and groups who would be most affected by specific conservation measures or who must take action to implement them, assessment of the nature of these impacts and involvements, and investigation of methods by which the interests of such participants can be included in the policy formation and implementation process. Examples of relevant questions are: how are habits regarding use of appliances, automobiles, and other energy-consuming devices formed and changed; how can consumers be motivated and educated to consider life-cycle costs rather than only first costs of purchases; how have consumers actually responded to the changing energy situation of 1973, in terms of identified motivations and specific energy-conserving actions.

The proper relative roles of government and the private sector in implementing energy conservation is an important and controversial question. The government's massive support of R&D helps to overcome economic barriers, but does not ensure implementation. There is considerable uncertainty and disagreement about the efficacy and necessity of government energy-efficiency regulation, such as energy-performance standards for vehicles and appliances, and stricter building performance standards and building codes. Other possible government roles are providing information for consumers, businesses, and communities (e.g., energy extension services). All need study.

D. Socio-economic Impacts of Conservation

Capital, materials, and labor are required for implementation of energy conservation measures that involve change-over to more energy-efficient capital stock. This causes an increase in economic activity. As energy consumption is subsequently moderated by these measures, requirements for energy resources and attendant materials and labor may decrease. These first order effects lead to multistage expansions and contractions throughout the economy, including perhaps effects on interest rates and the availability of financial resources for further investment. The net impacts are likely to vary among conservation measures as well as from broad policies or programs. An understanding of these impacts can assist in the design of economically efficient policies.

For the most part, energy conservation has fewer undesirable environmental and health impacts than supply strategies to provide equivalent energy. At some level of application, however, conservation would give rise to indirect socioeconomic and political effects, mostly through economic adversity, that would predominate over the direct benefits. Current technical and economic analyses suggest that this point is a long way from where we are now, possibly at an E/GNP ratio of 1/3 to 1/2 of present values (1). Because of the extreme importance of this issue, continuing study of the fundamental relationships between energy consumption and economic activity is important. Basic studies in energy/economy modeling are required, and in this connection studies should be pursued of fundamentally important economic parameters such as the long-term price elasticity, substitutabilities of energy demand, and the impacts of energy supplies and prices on productivity.

There is considerable uncertainty about the distributional and equity impacts of energy conservation measures. For example, any measures that directly or indirectly raise energy prices will differentially affect poor people. Distribution should not be used as an excuse to forego conservation, but it must be analyzed so that it can be dealt with by simultaneous compensatory measures.

E. Long-Term Energy Demand

Gaining an understanding of long-term energy demand -- the practical and economic limits to the physical efficiency of energy and materials use -- is an important and neglected element of the energy problem. Basic research is needed that would lead to improving energy-use efficiency in fundamental ways, that would examine the social effects of substituting one means to supply consumer amenities by others, that would look at the relationship of long-term world energy needs to U.S. supply and demand and to the global situation. Fundamental information is needed about possibilities for geographical rearrangement of man's activities, recycling of materials, enhanced product repair and reuse, and the development of extremely energy-efficient structures and products.

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