POTENTIAL FOR ENERGY CONSERVATION
IN THE
UNITED STATES: 1979-1985

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Committee on Energy Conservation

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of
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INTRODUCTION

On July 23, 1973, the Secretary of the Interior wrote to the National Petroleum Council (see Appendix A):

> In order to further assist us in assessing the patterns of future U.S. energy use, the National Petroleum Council is requested to conduct a study which would analyze and report on the possibilities for energy conservation in the United States and the impact of such measures on the future energy posture of the Nation.

In response to the request of the Secretary of the Interior, and in accordance with its established procedures, the National Petroleum Council formed a Committee on Energy Conservation under the chairmanship of Mr. M. F. Granville, Chairman of the Board, Texaco Inc. The committee was assisted by a coordinating subcommittee chaired by Mr. R. C. McCay, Vice President, Texaco Inc., and six task groups. The task groups were responsible for developing detailed analysis in the following areas: Patterns of Consumption/Energy Demand; Industrial; Residential/Commercial; Transportation; Electric Utility; and Consumer Concerns. (See Appendix B for Committee and Task Group Rosters.)

The Patterns of Consumption/Energy Demand Task Group developed demand projections which serve as a "benchmark" against which the effects of energy conservation proposals of the four end-use sector task groups can be compared. The Consumer Task Group was formed in order that consumer and public interests might be represented in the preparation of this study. This report does not include a separate chapter on consumer and public interest; however, the comments and concerns of the members of the Consumer Task Group are recognized and considered throughout the report. Consumer concerns were particularly directed to the conservation potentials identified and their impact on the public and society in general.

It is recognized that while many members of the National Petroleum Council have knowledge of operations relating to all areas of end-use energy conservation, not all members have the requisite expertise to deal with all aspects of this report. In the course of this study, wide industry (nonpetroleum) participation and support was solicited and utilized. In addition, this report was circulated, in draft form, to numerous industry and trade associations for their review and comments prior to the completion of this study. (See Appendix C for a List of Industry and Trade Associations contacted.) The comments received from these organizations have been carefully considered and incorporated in this report as appropriate.

> *The National Petroleum Council recommends that if this report does not fully reflect the views on energy conservation of a particular industry or trade association or other interested groups, such views should be expressed directly to the Secretary of the Interior for his consideration.*

The report is the third and final volume of the National Petroleum Council's study on energy conservation. The previous two volumes and four task group reports dealt with potentials for energy conservation in the near term (1974-1978).* The conservation potentials discussed in this report are directed toward future technological changes in the patterns of energy use and concentrate on the period 1979-1985 and beyond. The energy conservation potentials identified in Phase I (1974-1978) are presumed to continue and extend into the Phase II (1979-1985) period. The Phase II work has expanded the earlier work with emphasis on the impact of technology on energy use. For reference, the "Introduction" and "Summary" sections of the Phase I (Full Report) are included in Appendix D.

Throughout these reports, the National Petroleum Council has considered three principal approaches to energy conservation:

- Measures that reduce the consumption of energy by reducing the level of services provided or reducing the level of activities performed.
- Measures that increase the efficiency of energy utilization thus reducing consumption without reducing the level of services or activities.
- Measures that would permit substitution of more plentiful energy resources for those in scarce supply in the generation of electric power.

All three types of measures must be pursued vigorously so energy conservation will achieve its proper role in the Nation's overall energy future. Measures in the first two categories were considered in Phase I of this study, while the second and third categories are the major focus of this report.

The Phase II report examines technological developments that may contribute to energy conservation in the period beyond 1979. Estimates and projections of total possible "conservation" and absolute levels of future energy consumption have been avoided for a number of reasons. First, it was not possible within the context of this study to evaluate the economic and social acceptability of all the various technological possibilities examined and to combine them into internally consistent projections. And secondly, reduction in energy use as evidenced by absolute consumption levels may not represent the impact of "conservation," particularly where such reductions are the result of a slowdown of economic activity or the failure to attain optimum levels of economic growth. As a consequence, this study is not a projection of absolute energy conservation achievable but rather a discussion of energy conservation potential.

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* The previous publications on energy conservation are titled as follows: *Energy Conservation in the United States: Short Term Potential, 1974-1978* (Interim Report); *Potential for Energy Conservation in the United States: 1974-1978* (Full Report); and Industrial, Residential/Commercial, Transportation, and Electric Utility Task Group Reports.

SUMMARY

In the era of seemingly plentiful and inexpensive energy that has now ended, the pressures to utilize the more energy-efficient equipment and processes that were available and being developed were not as compelling as those currently being generated by the higher costs of energy and the prospects that energy in its familiar forms may be limited in the future. There will be forces resisting changes in energy use patterns. These forces will stem from: first cost considerations; capital availability; difficulities of providing sound technological assessments of proposed measures; availability of qualified technical manpower; rate at which changes can be made in existing modes of consumption; and desirability of other priorities. These factors will have to be balanced, and as a result, difficult choices may have to be made through the political processes of a free Nation.

PARAMETERS OF STUDY

A U.S. energy demand projection based on the continuation of the historic trends of the early 1970's was developed for this study. This projection was used as the "benchmark" for estimating conservation potential and titled "Past Trends-Continue case."

The Past Trends-Continue projections shown in Tables 1 and 2 are out of date, and do not fully take into account major factors of the recent few years such as the Arab oil embargo of 1973-1974, greatly increased energy costs or the economic recession of 1974-1975. In this time of rapid change, it is doubtful that a generally agreed upon projection could be developed. The Past Trends-Continue case is displayed as a comparison standard only. For example, assuming no change in the "real" cost of energy, the standard projection indicates that compact automobiles (under 3,200 pounds) would increase from the 1972 automobile population level of 29 percent to 38 percent in 1985. How this trend could be further accelerated is the subject of the Transportation Chapter. Other areas of change are also implicit in the standard projection.

The intermediate demand projection found in the December 1972, U.S. Energy Outlook Report is the basis of the Past Trends-Continue Case.* This projection was based on: economic growth in terms of real Gross National Product (GNP) at a rate of 4.2 percent per year; no future changes in real unit energy costs; population growth of 1.1 percent per year; increased energy use for environmental protection; no changes in basic environmental laws in existence in 1972; and improved technology for fuel substitution, and no capital limitations restricting growth.

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* National Petroleum Council, *U.S. Energy Outlook--A Report of the National Petroleum Council's Committee on U.S. Energy Outlook*, Washington, D.C.: December 1972. Hereinafter referred to as U.S. Energy Outlook Report.

TABLE 1

U.S. ENERGY DEMAND PROJECTIONS
PAST TRENDS-CONTINUE CASE
(Quadrillion BTU's)

	1972 Actual*	1978	1980	1985
Residential	10.5	12.8	13.6	15.5
Heating	7.0	8.2	8.6	9.6
Other	3.5	4.6	5.0	5.9
Commercial	6.2	7.9	8.6	10.6
Industrial	21.9	25.4	26.3	30.2
Nonenergy	3.7	5.7	6.6	8.6
Transportation	17.8	21.8	23.6	27.8
Passenger Cars	9.4	11.6	12.5	14.6
Trucks and Buses	4.0	4.9	5.4	6.4
Aircraft	2.0	2.7	3.1	4.0
Other	2.4	2.6	2.6	2.8
Electricity Conversion†	13.1	19.8	22.7	30.1
Total Energy Consumption	73.2	93.4	101.4	122.8

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* The 1972 actual energy demand differs from that developed by the Bureau of Mines because slightly different energy-fuel conversion factors and sector definitions were used.

† This category includes only energy losses in generation, transmission, and distribution. *Electricity consumption* is included in the appropriate sector above, as shown in the following memorandum, converted @ 3,412 BTU's per kilowatt hour.

	1972 Actual	1978	1980	1985
Residential	1.84	2.83	3.26	4.31
Commercial	1.22	1.96	2.30	3.18
Industrial	2.38	3.43	3.89	5.28
Total Electricity Use	5.44	8.22	9.45	12.77
Total Electricity Losses (Percent of Utility Inputs)	70.5	70.7	70.6	70.2

TABLE 2

ECONOMIC ASSUMPTIONS FOR ENERGY DEMAND PROJECTION
PAST TRENDS-CONTINUE CASE

	1972*	1978	1980	1985
Gross National Product (GNP) (Billion 1972 Dollars)	1,152.2	1,474.8	1,601.3	1,967.0
Disposable Personal Income (DPI) (Billion 1972 Dollars)	797.0	1,021.4	1,098.9	1,320.0
Industrial Production (Federal Reserve Board Index 1967=100)	115.1	151.5	164.4	202.2
Energy Cost--Primary (Wellhead, Mine, etc.) (Percent of 1970)	100.0	100.0	100.0	100.0
Population (Millions)	208.8	221.7	226.1	237.6
Civilian Labor Force (Millions)	88.6	96.6	99.2	105.6
Households† (Millions)	65.3	73.9	76.7	83.0
Single Family Dwellings (Millions)	47.6	51.9	53.2	55.7
Occupancy Rate (Percent)	91.3	91.1	91.1	91.5
Automobile Population (Millions)	86.3	105.2	111.6	126.1
Standard--Above 4,000 lbs. (Percent)	30.0	28.8	27.5	26.2
Intermediate--3,200-4,000 lbs. (Percent)	41.0	37.9	37.2	35.9
Compact, etc.--Below 3,200 lbs. (Percent)	29.0	33.3	35.3	37.9
Automobile Efficiency (Miles per Gallon)	13.4	12.6	12.6	12.6
Truck Ton Miles (Billions)	451.0	592.0	651.0	808.0

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*Some 1972 figures have been revised since calculations for the Past Trends-Continue case were completed and any revisions are not reflected above.

†Families, people who live together, and individuals living alone.

All assumptions for this case were accepted for developing the comparison standard except for population growth rate which was reduced to 1.0 percent per year. This change was made because of recent data tending to confirm a lower population growth rate consistent with the August 1970, Schedule E of the Census Bureau. The energy demand adjustment for this lower rate was the subject of a supporting study in the U.S. Energy Outlook Report. It also appears now that the original projections of GNP, Disposable Personal Income, and Industrial Production for 1978, 1980, and 1985 are too high. Although the recent prolonged recession has deflected the growth path of the economy (and of energy consumption) below that required to reach these projections, it was decided not to adjust these parameters in order to preserve the direct comparability between earlier analyses and this study. However, it must be pointed out that to the extent that the economic projections are not reached, the associated energy demands would be less and the potential reductions in energy consumption, due to conservation measures cited in this report, could be overstated. The percentage reductions would, however, remain about the same.

Table 1 shows the Past Trends-Continue energy assessment for 1978, 1980 and 1985 while Table 2 indicates some of the major parameters behind the energy assessment. Factors on Table 2 other than GNP, population, and energy costs were not covered in detail in the U.S. Energy Outlook Report, but are estimates thought to be consistent with the earlier energy demand projection. These additional data are based on independent assessments by study participants and were compiled on a consensus basis. The individual estimates were tabulated by the NPC staff and were not revealed to the study participants.

In order to examine conservation potentials in specific consuming sectors, energy demand data for 1972 are divided on slightly different bases in other sections of this report. The Transportation analysis (Chapter Three) includes some miscellaneous categories (about 1.0 quadrillion BTU's) that are shown in the industrial sector in Table 1. The Industrial Chapter (Chapter One) considers "nonenergy" uses (3.7 quadrillion BTU's) which increase the 1972 industrial consumption estimate to 24.3 quadrillion BTU's. Table 1 data include energy used in all dwellings in the residential sector while the "Residential" section of Chapter Two includes only structures containing one or two families in its analysis. Energy consumed in dwelling units for three or more families is accounted for in the "Commercial" section of Chapter Two. The above adjustments are shown in Figure 1.

INDUSTRIAL

Projected Phase I energy savings by 1978 of about 10 percent per unit of output in the industrial sector, based on 1972 energy consumption, are assumed to carry through into Phase II. A number of activities are in progress which should evoke considerable attention to industrial energy consumption. Not the least of these is the current attention focused on the energy problem by the news media. Repetitive publicity and higher energy costs have not only

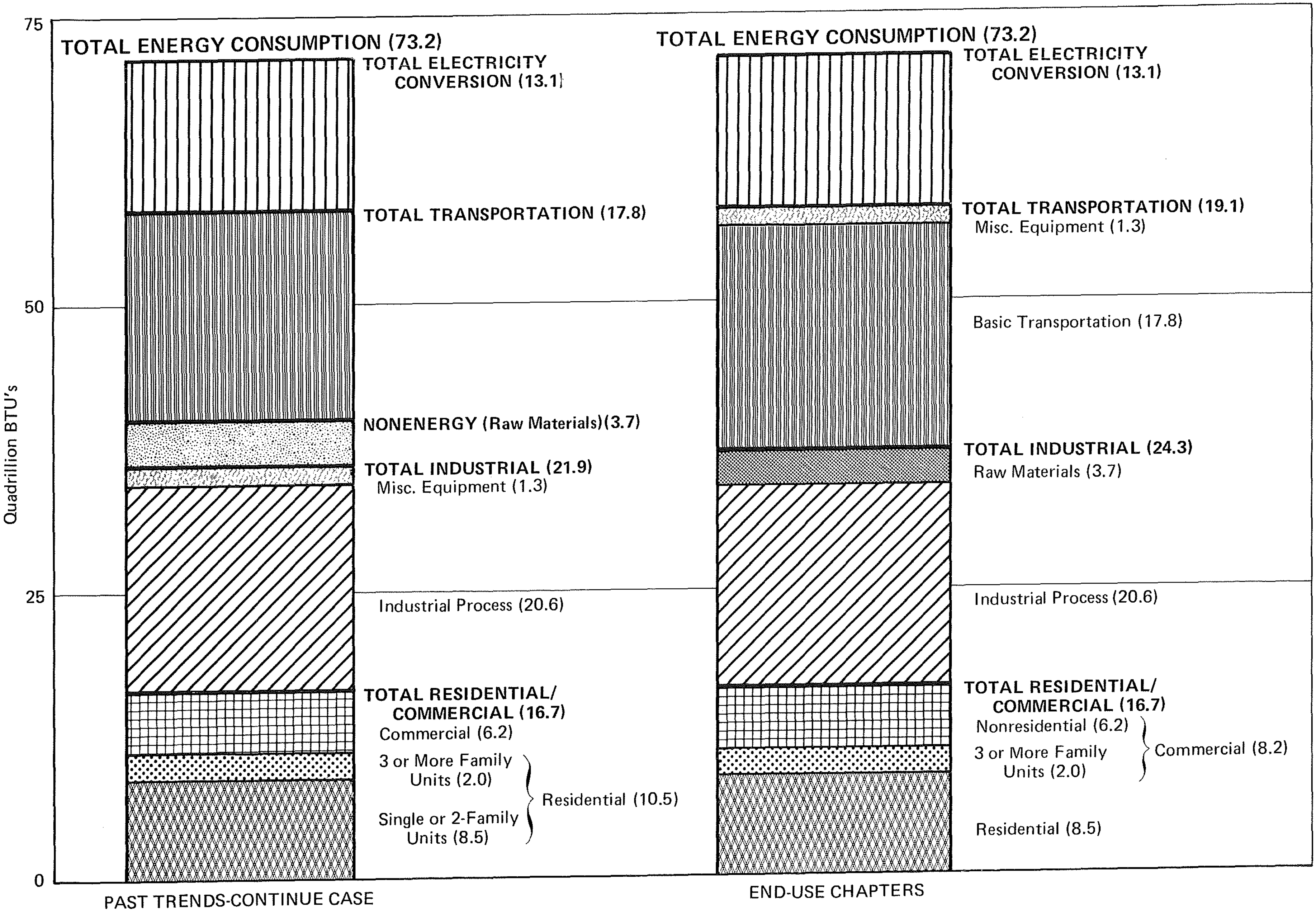

Figure 1. U.S. Energy Consumption--1972 Comparison of Past-Trends Continue Case *Versus* End-Use Chapters Analyses.

attracted the attention of end-users, but their research and development (R&D) organizations, engineering contractors, and new equipment designers and manufacturers as well. Numerous energy conservation consultants have emerged recently, some operating under governmental auspices, who are engaged in preparing and distributing conservation checklists and awareness bulletins. This information should provide incentives for the development of future energy conservation programs with particular value to the smaller industries. Also surfacing are engineering firms interested in providing technical assistance for on-going programs or in developing new programs. Wider use of currently available and developing technology throughout industry could increase energy conservation during Phase II.

Some examples of technological developments that may contribute are:

- New processes which include continuous casting of steel, improved smelting of aluminum, and suspension pre-heater kilns in cement manufacture.
- Adjustment in product requirements or substitutions of products to take advantage of lessened energy intensiveness where possible.
- Bottoming cycles for the recovery of low level heat.
- Improved refrigeration, heating, and separation methods, and microwave oven drying in food processing.
- Joint industrial/residential/commercial complexes to utilize otherwise rejected low level energy for heating and cooling.
- More efficient in-plant power generation and improved heaters and heat exchangers.
- Fluidized-bed combustion of coal.

Some high gains in efficiency of energy use are shown in areas of limited savings potentials. The complex and extensive operations in the industrial sector preclude quantification of the total energy savings or total conservation potential during the 1979-1985 period.

RESIDENTIAL AND COMMERCIAL

Energy savings in the residential and commercial sectors during the 1979-1985 period can develop in three areas: (1) existing housing and buildings--reflecting a continuation of savings as quantified in Phase I; (2) new construction--embodying improved techniques; and (3) more efficient appliances, equipment, and systems.

The principal factors influencing the thermal efficiency of housing and buildings are: glass area, insulation, exterior solar shading, building orientation and landscaping, appliances and equipment used for space heating and cooling, water heating, lighting and other services.

Some technological factors that could affect conservation in both the residential and commercial areas are:

- More efficient heating and air conditioning systems, water heaters, refrigerator-freezers, ranges, and lighting systems.
- Waste heat reclamation from refrigerating systems, water heating systems, and exhaust air by means of improved heat exchangers.
- Use of reflective glass and more widespread use of zone control space heating and cooling systems.
- Development and use of improved components for total energy systems which includes wider application of absorption refrigeration.
- Development of heat actuated heat pumps and refrigerants with improved efficiency.
- Development of geothermal and solar energy equipment which includes on-site wind-powered and solar photovoltaic electricity generation.

TRANSPORTATION

Basic modes of transportation include: highway, airway, railway, waterway, urban public transit, and pipeline systems. Energy savings in these modes can be made by: (1) reduced levels of service; (2) technological improvements and innovations; and (3) modifications of transportation utilization patterns.

The major short-term conservation opportunities identified in Phase I were in the highway mode. This mode has the highest level of energy consumption in the transportation sector. During the Phase II period, sufficient technological advances appear applicable in the highway mode and can be used to generate a larger percentage of savings than in other modes. Based on available and developing technology in the various modes, some avenues of potential savings are:

- Reduced passenger car engine power requirement including reduction in vehicle weight, modified axles and transmissions, reductions in aerodynamic drag, greater use of radial tires, and more efficient accessories.
- Use of smaller cars.
- Continued improvements in engine efficiencies for passenger car service.
- Changes in travel characteristics which include improved automobile traffic flow and increased carpooling.

- Improvements in truck design and freight handling and operational procedures.

- Extended use of more efficient aircraft engines and wide-bodied aircraft and improved aircraft utilization. Technological advances in aerodynamics, materials, and equipment for traffic and flight control.

- Expanded use of computerized management controls in railroads to optimize loading, speeds, and rates of fuel consumption.

- Use of more efficient power plants, larger displacement hulls, improved hull design to reduce drag, and improved cargo handling procedures in waterborne transportation.

- Expanded use of buses in urban transit systems and vans in carpooling.

- Improved efficiency through use of larger pipe sizes in pipeline operations, friction reduction techniques, and advances in pump and compressor design.

ELECTRIC UTILITY

Primary emphasis in Phase II is placed on energy conservation potentials resulting from technological changes that can be introduced in the 1980's. Attention is given to longer term concepts and to possible avenues for substitution of fuels.

Some examples of energy conservation potentials related to technological application and development by electric utilities are:

- Waste heat utilization, particularly in steam-turbine/combustion-turbine cycles which are considered to offer the greatest potential for conservation in the generation of electricity in the 1980's. Increases in efficiency of current best combined-cycle plants from about 39 percent to 50 percent are anticipated by 1985.

- Average annual efficiency for existing fossil fueled steam cycle units is about 32.7 percent, while that of light-water nuclear units currently operating is about 30.5 percent. The most modern steam plants have efficiencies of about 38 percent. Technology exists to increase efficiencies of both steam cycle and nuclear units to about 40 percent.

- Only small fossil fuel savings will stem from the development and use of fuel cells and geothermal energy in the Phase II period. Over the longer term, added savings lie in the development of solar generation of electricity.

- Technology is available for the High Temperature Gas Cooled Reactor (HTGR) which should be entering the market in the 1980's. Technology is also available for the breeder reactor, but commercial development will not be achieved until after 1985. Thermonuclear fusion may be forthcoming in the distant future.

- Combined district heating and power systems resulting from utility/industry/residential/commercial complexes can have thermal efficiencies as high as 80 percent. However, the number of possibilities for such combined applications is relatively limited and, even when possible, the utilities involved must still be prepared to provide at least some emergency back-up service.

- Energy storage applications with limited potential for conservation in the 1980's include pumped hydroelectric and compressed air storage.

- Potential energy savings in the areas of transmission and distribution are small through 1985. Subsequent development and use of ultra high voltage, direct current, and cryogenic cable transmission may offer large potential savings.

FURTHER OBSERVATIONS AND COMMENTS

During the course of this study, which included the period encompassing the Arab oil embargo of late 1973 and early 1974, it has become evident that the role of energy in our society is not universally understood. Some groups have apparently overlooked the fact that U.S. economic growth and standard of living improvements have been closely correlated with increasing energy consumption. Instead, it has been suggested that the United States has been guilty of widespread "waste" of the world's energy resources. "Waste" is an economic/social concept. Prior to the energy price increases of 1973/1974, the U.S. economic/social structure was developed by substituting energy for labor; thereby, improving economic productivity, providing more leisure time, and improving the standard of living. Society, as it existed at that time, was a product of its past economic environment.

Today, energy prices have increased and some of the energy related practices that were economically efficient are no longer so. Obviously, changes in energy use patterns should occur. However, many current energy use patterns of the United States cannot be changed in a few years without severe economic and social penalties.

Energy conservation is part of the answer to the general question of future U.S. energy posture. However, energy conservation is only one facet which should be considered in conjunction with continuing development of energy supplies. Every published forecast to date of the U.S. energy requirements in 1985 indicates that more energy will be required than is being consumed today--even with lower economic growth rates and substantial energy conservation achievements. Most investigations into domestic energy independence indicate that even with foreseeable reductions in the rate of energy consumption, the United States is expected to be at least partially dependent on foreign energy supplies in the future.

Conservation of energy should be an integral part of an overall national energy policy after proper consideration and debate regarding other national priorities such as economic growth, alleviation of unemployment, social welfare, environment, national security, balance of payments, etc. Policies which are in conflict with energy conservation and which fail to allow individual freedom of choice should be carefully evaluated.

Trade-offs between capital costs and energy costs are common, and this report emphasizes the front-end capital requirements of energy conservation measures. The corollary of this is also worthy of note: a shortage of capital which causes deferral of conservation-oriented expenditures often will have to be compensated for by extraordinarily heavy demands upon fossil energy sources, and particularly upon petroleum. Deferral of needed investments in utility generating capacity calling for use of nonpetroleum fuels (nuclear and coal) may result in later emergency installation of turbine facilities requiring petroleum fuels.

It should not be assumed that increased energy savings necessarily result in economic savings for consumers. Through enforced conservation standards, the consumer could be required to install or indirectly pay for installation of more capital equipment than the resultant energy cost savings would pay for. A good example of this is installation of solar heating requiring conventional heating backup. In this case the energy supplier would have to provide standby capability which the consumer would have to pay for. The net result might be higher costs (including the consumer's cost of capital) than heating directly with oil, gas or electricity.

This report does not attempt to evaluate any tendency of consumers to transfer the economic savings afforded by conservation measures to other energy uses. For example, automobile mileage driven may tend to increase as miles per gallon performance improves.

Energy use patterns will differ for each geographic region and end-use sector. Mandated reductions of energy use could create hardships in certain regions and sectors of our society. Within this framework, the marketplace, which has long been one of the most efficient allocators of scarce supplies, should be allowed to eliminate the inefficient uses of energy. While distortions are occasionally imposed upon the market by external events, such as the recent Arab oil embargo or government intervention, the system should be allowed to clear the inefficient uses of energy and only should be supplemented by public policy decisions when and if there are obvious and untenable inequities in the sharing of the burdens which may be involved. The overriding goal should be to preserve the freedom of the individual to select his options to fit his needs and resources.*

Functioning of the market may not eliminate some inefficient uses of energy as long as some sources of energy supply continue to be subject to regulatory actions which cause misallocation of resources. This must be taken into account in consideration of public energy policy.

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* Mandatory and curtailment measures to achieve energy conservation are discussed in the NPC's *Emergency Preparedness for Petroleum Imports into the United States*, Washington, D.C.: September 1974.

Chapter One

INDUSTRIAL

Historically, the industrial sector has significantly increased its energy efficiency. As reported by the Conference Board, industrial energy use per unit of output declined at a 1.6 percent average annual rate from 1954 to 1967.* This trend is likely to accelerate in the future.

In order to determine the extent to which industry as a whole could effect energy conservation, eight industries which account for the major portion of the energy used in the industrial sector were selected for evaluation. These industries are:

- Chemical
- Iron and Steel
- Agriculture
- Food Processing
- Petroleum
- Paper
- Aluminum
- Cement.

Opportunities for improving efficiency of steam-generator industrial boiler systems which comprise almost one-half of the energy consumed by industry are also considered.

The Phase I report projected an overall industrial sector energy savings for the 1974-1978 time frame of approximately 10 percent per unit of output.† The savings per unit of output was based on 1972 energy consumption and varied significantly between industries. Energy savings ranged from 20 percent for the most heavily energy intensive industries to 2 percent for farming operations. The various estimated energy savings for the industry groups became more significant as a result of the Federal Energy Administration's (FEA) Voluntary Conservation Program initiated in September 1974. At that time, representatives of the FEA and the Department of Commerce met

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*The Conference Board, *Energy Consumption in Manufacturing, A Report to the Energy Policy Project,* "Summary" section, Cambridge, Mass.: Ballinger, 1974.

†National Petroleum Council, *Potential for Energy Conservation in the United States: 1974-1978,* Washington, D.C.: September 10, 1974, pp. 27-47.

with petroleum industry executives in the first of six Industry Conservation Conferences. These conferences were aimed at soliciting voluntary commitments for developing comprehensive conservation programs. The petroleum industry pledged a refinery energy conservation goal of 15 percent by 1980. In later conferences with representatives of the cement, aluminum, chemical, steel, and paper industries, the projected energy reductions generally followed the conservation potentials identified in Phase I. Periodic reporting of achievements by each industry group to the FEA should stimulate conservation activities. The first of these reports was scheduled to cover the January 1 through June 30, 1975 operating period.

The 10 percent per unit of output reduction in energy use in Phase I amounts to about 2.20 quadrillion British Thermal Units (BTU's) per year. This saving, if converted from the various forms of energy (coal, gas, coke, etc.), to an equivalent in oil would amount to approximately 1 million barrels a day by 1979. Essentially, all these energy gains should apply during Phase II. Retrogression into inefficient operating conditions is not anticipated since these gains will have been made through capital expenditures induced by higher energy prices and because of continued management interest in monitoring operating costs. The total energy savings during the period may vary somewhat depending upon the state of the economy.

Conservation activities implemented during the 1974-1978 period that will carry through into Phase II are:

- Physical changes or additions to plant equipment to recover heat or to reduce operating energy requirements.
- Operational savings such as reducing unnecessary idling of equipment, reducing excessive process overdrying, and optimizing the reflux and recycle ratios in refineries and chemical plants.
- Maintenance activities such as steam leak and insulation repairs, frequent cleaning of exchangers, and refractory repairs in heaters and boilers.
- Control of losses and waste such as using wood refuse, cutting oil, and solid wastes as fuels, and reducing hydrocarbon losses to flares or vents.
- Intensified operator surveillance and supervisory controls to improve operating efficiency and reduce wastes.

A number of activities are in progress which should evoke considerable attention to industrial energy consumption. Not the least of these is the current attention focused on the energy problem by the news media. Repetitive publicity and higher energy prices have not only attracted the attention of end-users but research and development (R&D) organizations, engineering contractors, and new equipment designers and manufacturers as well. Numerous energy conservation consultants have emerged recently, some operating under governmental auspices, who are engaged in preparing and distributing conservation checklists and awareness bulletins. This information should provide incentives for the development of future energy conservation programs with particular value to the smaller industries. Also surfacing are engineering firms interested in providing technical assistance for on-going programs or in developing new programs.

The major incentive for continuing energy conservation programs is the cost of energy. Since 1971, industry energy prices have risen more rapidly than most other operating and maintenance costs. The challenge offered by these rising energy costs should assure continued activity in the following areas:

- Re-evaluation of plant operation with proper surveillance.
- Use of R&D organizations to explore for new processes and methods which are less energy intensive.
- Search for energy conservation projects which will be economically attractive.

CONSERVATION IN THE 1979-1985 PERIOD

Energy conservation gains made during Phase I are expected to be sustained during the 1979-1985 period. In addition, the development and implementation of new technology in the various industries will result in substantial conservation potential. Some examples of these new developments are:

- New processes which include continuous casting of steel, improved smelting of aluminum, and suspension pre-heater kilns in cement manufacture.
- Adjustment in product requirements or substitutions of products to take advantage of lessened energy intensiveness where possible.
- Bottoming cycles for the recovery of low level heat.
- Improved refrigeration, heating, and separation methods, and microwave oven drying in food processing.
- Joint industrial/residential/commercial complexes to utilize otherwise rejected low level energy for heating and cooling.
- More efficient in-plant power generation and improved heaters and heat exchangers.
- Fluidized-bed combustion of coal.

CONSTRAINTS

The availability of capital and technical manpower will continue to be the major constraints in implementing energy conservation projects through the 1979-1985 period. Additional energy demands that may be required for some desirable safety and environmental projects could offset some of the conservation gains.

Capital

New technology that is developed could be capital intensive, especially if it entails replacement of complete operating units. Rising construction costs will moderate the economic incentive of new energy saving developments. In addition, conservation projects within any individual company will have to compete for the required capital with other needs such as plant expansions, environmental improvements, and plant revisions resulting from product changes.

Availability of Technical Manpower

During the short-term period considerable energy conservation can be achieved by surveillance of operations. This can be effected through the use of knowledgeable nontechnical personnel and should continue in the 1979-1985 period. Increased use of well trained people will provide further opportunity for energy savings. However, for the more sophisticated activities, technical manpower must be dedicated to this effort. There still exists the strong industry concern expressed in the Phase I report regarding the availability of technical manpower to identify, evaluate, and implement energy conservation projects. However, the movement of consultants and engineering firms into this field should provide the needed assistance to industry. For "breakthrough" ideas, in-depth research will be required by the industries and possibly, the academic sectors. The extent of dedication and results of this effort will determine the energy conservation achievements in the 1979-1985 time frame.

Environmental and Safety Requirements

Environmental and safety requirements of the early 1980's may increase industry's energy demands and offset some of the energy conservation achievements. For example, implementation of "zero discharge," the national goal of the 1972 Federal Water Pollution Control Law, could result in increased energy consumption.

TRADE-OFFS

In some cases, energy conservation opportunities in industry involve certain trade-offs which should be considered in the overall evaluation. Some examples are:

- *Agriculture:* Although "no-till" farming will reduce energy requirements, it could also reduce the demand for mechanized farm equipment and thus increase unemployment in the farm machinery industry.

- *Steel:* If some of our exported scrap could be recycled in our existing mills, energy savings would result. However, decreasing our scrap exports would affect balance of payments and international trade relations.

NEW AND IMPROVED TECHNOLOGY FOR INDUSTRY

Rather than attempting to cover all new technologies, specific examples under development which can be utilized during the 1979-1985 period were selected for each of the industrial sectors. These are discussed in the following sections. Unexpected breakthroughs may occur in various areas but the effects cannot be evaluated. It should be noted that some of the examples are applicable to more than one industry and exchange of technologies between industries should be encouraged.

CHEMICAL INDUSTRY

Development of new technology has been a major factor in the growth of the chemical industry to date and is expected to continue to play an important role in the future. Application of new technology in areas such as separation systems and new chemical synthesis routes will have a bearing on reduced energy usage. Current examples under development are nonthermal separation processes such as liquid-liquid extraction or reverse osmosis. In addition, new, less energy-intensive, higher yield synthesis processes continue to receive major attention in individual laboratories.

New technology should contribute significantly, particularly in new plants that are economically optimized, to reflect the new, high cost of energy. But there is another area where significant potential energy savings could be achieved through the application of existing technology. The chemical industry is one of the country's major consumers of both steam and electric power. In 1967 the chemical industry's estimated steam consumption was 1.3 trillion pounds per year and the estimated peak electrical power load was 15,000 megawatts (MW). Of the 15,000 MW electric power requirement referred to above, the chemical industry generated only about 2,900 MW, or less than 20 percent of its demand. The chemical industry accounts for about 20 percent of total industrial energy consumption. The high load factor of both steam and power in the chemical industry indicates that the combined production (dual purpose plants) of process steam and electric power could produce both energy savings and environmental benefits.

Industrial processes which utilize steam typically generate it by means of low pressure, package boilers which operate at a relatively low thermal efficiency. In these cases, the potential exists for the use of high pressure boilers with their relatively high fuel efficiency, followed by back-pressure turbines through which the steam passes while being reduced to the desired process pressure. The turbine drives a generator and by-product electric power is produced. The energy required to produce this power is greatly reduced in comparison with conventional central station plants in which the exhaust steam is condensed and the heat content rejected to the environment. The combined steam/electric plants are referred to as "dual purpose" and appear favorable on the basis of both fuel and environmental considerations.

In some cases, instead of using steam for electric generation, the steam is expanded through mechanical drive turbines prior to its use in the process. This utilization of energy is as efficient as if the steam were expanded through turbines driving electric generators prior to its use in the process. Some dual purpose plants have been successfully utilized in the chemical industry, among others, for 40 years or more. However, there is a larger potential for such plants than has been realized to date. Several factors account for this:

- Small size of some unit plants making economical dual purpose operation impractical.
- Gradual evolution of plants at a given site in which incremental additions of dual purpose capacity were not practical.
- Historically favorable rates for the purchase of power from local utilities.
- Industrial management reluctance to add the burden of power generation to the industrial operation.
- Low fuel cost which discouraged additional capital investment to save fuel.

Plant size is a major consideration when introducing the dual purpose design. It is estimated that a steam capacity of at least 400,000 pounds per hour is needed to justify the addition of electric generating capacity to a boiler. In 1967, some 46 percent of the chemical plants had steam capacity requirements greater than 400,000 pounds per hour. Thus, in 1967, the chemical industry theoretically had the capability of economically generating about 8,700 MW of electricity--about three times the actual generation.

Constraints

One of the inhibiting factors to utilization of dual purpose operations is the evolutionary growth of many chemical plants. Other constraints in this area include capital availability and environmental factors. With more careful energy planning, future plants can be designed and constructed with this energy and environmental savings in mind. The earliest this new construction could be completed is 1978 and thus, the energy conservation potential through dual purpose operations can be expected in the 1979-1985 time frame.

IRON AND STEEL INDUSTRY

Current practice in steelmaking involves the energy-intensive system of producing individual ingots which require frequent handling and reheat operations. Typically, liquid steel is tapped into a refractory-lined ladle; poured or teemed into cast iron ingot molds; the cast iron molds are stripped from the ingots after they have solidified; the ingots are heated to a uniform temperature of 2,200-2,400°F in fuel-fired soaking pits or furnaces; and the hot ingots are rolled into semifinished sizes which are later reheated and rolled into strip or shapes. This method is being modified as new plants are built or as obsolete plants are replaced by the more efficient continuous casting process.

Some measures that could conserve energy in the steel industry depend on developments in the metallurgical process technology in contrast to the energy process technology. One new process that is being utilized is the continuous casting of slabs, billets, etc., which saves energy in two important ways. First, the soaking pit and ingot rolling (slab mill) operations are eliminated, saving the fuel and electricity used in these operations. Second, in rolling ingots into semi-finished shapes both ends are sheared off since they contain defects. The sheared ends or crops may account for about 15 percent of the original ingot weight and are recycled through the melting furnaces. Continuous casting eliminates much of this recycling, improving yield.

Long-Term Energy Conservation Potential

Total industry data for soaking pit fuel consumption are not readily available. Wide variations are known to exist from plant to plant due to different operating practices. A reasonable estimate of the industry average is 1.2 million BTU's per ingot ton. An estimate of the average total energy requirements for ingot rolling is approximately 1.9 million BTU's per ingot ton.

The energy savings assignable to improved yield from continuous casting are derived from the energy required to produce raw steel. If it is assumed that this steel is produced from scrap in an electric furnace, then the yield increase results in energy savings on the order of 0.9 million BTU's per ton and is principally electrical energy. Total energy savings from continuous casting by eliminating ingot rolling and utilizing recycled scrap produced in an electric furnace would be about 2.8 million BTU's per ingot ton. This is equivalent to about 4 million BTU's per ton of steel products shipped.

Constraints

In 1973, approximately 11 million tons of steel were continuously cast. This figure has been increasing each year; however, there are many grades of steel that cannot be continuously cast so new technology and operating practices must be developed for these grades.

Based on American Iron and Steel Institute estimates, the capital cost of a continuous casting facility is about $70 per annual ton. Replacement of rolling mills by casting cannot be justified by fuel savings alone. However, as primary mills become obsolete, they will be replaced by casting facilities. Most additions of new steel capacity will undoubtedly include continuous casting.

AGRICULTURE

U.S. foods and feeds are now normally harvested from cultivated lands, representing over 300 million acres. Agricultural land tillage systems (preparation, fertilization, and planting) require large amounts of energy, primarily in the form of diesel and gasoline engine fuels. Significant energy savings through more efficient and better utilization of farm equipment will require continuing educational and training programs.

Conventional tillage systems for major U.S. crops (e.g., corn, soybeans, wheat) are multistep, involving such operations as plowing, planting, fertilizing, and cultivating. Each separate step consumes time and energy. Alternate systems, in which part or most of these separate operations have been eliminated or combined, are under research and development (R&D).

The generic term "no-till" is used to designate the maximum deviation from the conventional systems. Other intermediate systems are identified as combined tillage and planting, reduced plow, disc-plant, and many others. Application of one or more of these to such large-volume crops as corn and soybeans (approximately 75 and 50 million acres, respectively) will undoubtedly be achieved.

Long-Term Conservation Potential

Energy savings for new tillage systems have yet to be fully quantified and several years will be required to do so. Most of the new tillage systems' research has been applied to growing corn and soybeans. Preliminary findings indicate that complete use of no-till for these two commodities could result in fuel savings of 50 to 75 percent over conventional "till" methods. Annual energy savings of 14 to 21 million barrels of fuel (equivalent to .08 to .12 quadrillion BTU's) could result from the no-till approach. Further energy savings would be in proportion to increased use of this approach for other cultivated crops and increased use of land suitable for cultivation.

Constraints

The effects of no-till on crop yields, fertilizer, herbicides, chemicals, and equipment requirements have not been fully evaluated. Production losses could reduce or eliminate the energy savings. Possibly one of the intermediate procedures will prove most effective.

New systems could also have significant effects on the machinery industries. Less equipment and different type equipment will be required.

FOOD PROCESSING INDUSTRY

Processing of food and manufacturing of consumer food products are essential to the maintenance of a reliable and safe food supply system. Both depend heavily upon adequate supplies of energy in a variety of forms. The perishability of many farm products and their unsuitability for human consumption in their raw state require processing in order to preserve nutritional quality and to assure the desirability and safety of the consumers' food supply.

Energy consumption in the food manufacturing industry is directly linked to U.S. population growth and to advances in the standard of living. These factors apply both domestically and globally. Accordingly, while energy conservation savings can be anticipated on a BTU per ton basis in the years ahead, total energy consumed in the industry is likely to increase over time despite energy conservation efforts.

In practical terms, it is difficult to separate secondary activities in the food industry from food manufacturing per se. The energy conservation approaches discussed do not include activities in farming, transportation of materials to or from food processing plants, or energy expended in the production of packaging, equipment or other purchased materials.

Long-Term Conservation Potential

The food processing industry can probably achieve on the average, energy savings of between 10 and 15 percent per unit of output by 1978. This estimate does not assume substantial technological or industrial breakthroughs. In the Phase II time frame (1979-1985), additional savings of between 2 and 5 percent can be expected.

Because of the wide diversity of both products and processes which represent the food manufacturing industry, as well as the seasonal nature of much of the industry, there is no known body of data describing actual, theoretical, or obtainable efficiencies of existing systems either for the total industry or for any significant part of it.

Technologies either now being developed or not commonly practiced in the United States could be utilized in the 1979-1985 time frame and could produce substantial additional savings of energy. Among the most promising of these technologies are:

- *Membrane Concentration of Liquid Food:* Virtually no studies have been made on the energy requirements necessary for the membrane processing of liquid foods. However, extensive studies have been made on the various desalinization processes, so these figures can be used as a guideline for projecting possible areas where energy might be conserved. (See Appendix E, Exhibit I, Table 19 , regarding the energy requirements for six desalinization processes.) While no similar analysis is available on a food liquid system, it is clear that for purposes of comparison, the reverse osmosis process is one of the most efficient processes from an energy point of view.

- *Microwave Drying Process:* Combined microwave/air-drying systems are being studied as a more efficient method for drying vegetables (see Appendix E, Exhibit I, Table 20). Uses of these systems have been shown to achieve savings of up to 95 percent in energy required.

- *Improved Food Preservation Techniques:* Current food preservation techniques involve primarily the thermal treatment of foods. New methods that might involve, for example, radiation or chemical treatment may prove to be considerably less energy intensive.

- *Absorption Refrigeration:* Waste heat can be used to produce cooling systems to save energy.

The food processing industry also consumes large amounts of energy in treating its waste materials for disposal and has developed the Rotating Biological Surface (RBS) Waste Treatment Process which offers potential for energy savings. This biological purification of waste waters, containing biodegradable organic pollutants, offers some promising alternatives to conventional waste treatment techniques used in the food industry. Through proper engineering, the power requirement to operate this system should not be more than half the power consumed by the conventional activated sludge process.

Constraints

Energy conservation actions undertaken by individual food processing companies reflect, for the most part, limited capital expenditures and involve readily available measures. An objective cost benefit analysis of regulations and standards governing product process emissions and the work area might permit more efficient use of energy resources in many areas without unacceptable risk to the public or undue impairment of long range social and environmental goals. As in other industries, increases in the costs of individual fuels will undoubtedly provide further incentive to conserve as well as to convert to alternative sources of energy.

PETROLEUM REFINING

The refining process normally uses energy in the forms of: fuel gas, fuel oil, electric power, steam, and occasionally, solid fuels such as coal and coke. The processing of approximately 13 million barrels of crude oil (the 1974/1975 daily average) requires the equivalent of 1.3 million barrels of oil, or about 10 percent of the amount refined. Most of this energy is eventually rejected to air or water as low temperature waste heat. The sharply increased cost of fuels substantially increases the incentives to conserve and recover this energy.

In order to materially improve efficiencies, new and essentially untried methods will be required. As our traditional energy supplies decrease and become more valuable, an intensified R&D effort will be needed to develop the technology for useful recovery of low temperature waste heat and use of more plentiful fuels for process heat. Some R&D efforts under consideration are:

- Areas presently under investigation but which will require an intensive R&D effort to achieve economical and practical systems before 1985.

--Systems using absorption-mechanical cycles with ammonia-water, lithium bromide, or other working fluids in single or multi-stage configuration.

--Rankine cycle systems using fluorocarbons, butanes, or other compounds. These cycles will have to be improved in efficiency (now less than 20 percent) and tested for reliability. Other compounds with properties to improve cycle efficiency must be found and reliable equipment must be developed to make these processes economically operable.

--Low temperature heat storage (both on seasonal and hourly period scales) should be examined concurrently with studies of high temperature heat storage.

- Areas where significant R&D is not required but where planning and coordination among multiple users are needed.

--Feasible joint industrial complexes wherein companies are grouped by energy needs. Such a grouping might consist of an electric utility, a petroleum refinery, and a food processing complex.

--Joint industrial/commercial/residential complexes wherein low temperature waste heat for heating, cooling, etc., might be used.

These endeavors would require a high degree of coordination and would be primarily of a "grassroots" nature. This type of planning appears to be essential to achieving breakthroughs in energy utilization.

Long-Term Conservation Potential

Only a small portion of energy used in petroleum refining is consumed in chemical change and mechanical applications. Most heat is eventually rejected to the atmosphere or water as low level heat Table 3 shows energy rejection sources and temperatures in a representative modern refinery designed for efficient processing.

Using 100 percent as a base and 150°F as the lowest temperature limit for effectively recovering heat, 80 percent of the stack gas loss and 65 percent of the cooling and condensing energy loss is theoretically recoverable. Radiation and flare losses can be materially reduced by increased insulation and process revisions but the effect on overall recovery of energy would be minor. Of the total refinery energy consumed (1.3 million barrels per day) about 47 percent, or 600 thousand barrels per day could theoretically be recoverable as low level heat with further development of technology and with attendant capital expenditure.

Because this low level heat must be converted to mechanical energy at low efficiencies (12 percent), the actual percentage of fuel saved would be:

$$\frac{47\%\ \text{energy recoverable} \times 12\%\ \text{efficiency}}{40\%\ \text{normal power generation efficiency}} = 14\%\ \text{fuel saving.}$$

TABLE 3

REFINERY ENERGY REJECTION SOURCES AND TEMPERATURES

Source of Rejection	Temperature Level (°F)	Total Rejection (Percent)	Maximum Recoverable Energy (Percent)
Heater and Boiler Stack Gases	450	10	8
Cooling and Condensing of Process Streams	250	60	39
Steam Condensing	150	25	0
Radiation, Safety Flares, Vents, etc.	-	5	0
		100	47

The 14 percent fuel saving for the 1.3 million barrels per day used would be 180 thousand barrels per day compared to the theoretical 600 thousand barrels equivalent heat recovered.

Other Considerations

Substantial efforts to use the vast quantity of low level heat have not been limited to the petroleum industry. Chemical, metal, and other major industries have also been involved. Most of the energy input to any chemical or mechanical process is eventually rejected as low temperature heat. Reducing this unrecovered energy should be a major goal for future energy conservation research activities. However, further development of improved methods and equipment will be necessary in order to realize the potential savings in this field.

Research by universities offers potential for such development. Since the possibility of success for any one effort appears small, establishing many coordinated projects over a broad range of individual applications, at relatively low cost per project may be most productive. One major breakthrough could generate the needed momentum in the field of low temperature waste heat recovery.

PULP, PAPER AND PAPERBOARD INDUSTRY

Energy use per ton of output in the pulp and paper industry was projected to decline by some 15 percent during the Phase I period of this study. It is difficult to predict what new paper making technologies or changes in paper and paperboard products will actually make substantial contributions to energy conservation in the long run. However, some of these might include:

- New refining technologies to replace the current "hammer on anvil" approach
- More extensive use of thermo-mechanical pulping which generates higher fiber yields
- Improved chemical recovery systems for non-kraft pulping
- Freeze drying methods of concentrating black liquors
- Improved fiber yield per acre with increased efficiency
- Better techniques for recovering heat losses from air and water effluents
- Manufacture of lighter weight papers thereby conserving fiber
- Reduction in the brightness levels of paper thereby conserving the energy consumed in bleaching and in the manufacture of chlorine
- Combustion of more wood waste as a source of energy
- Increased recycling of paper which requires less total energy than paper manufactured from primary fibers but more purchased energy
- Increased integration of pulp and paper manufacture thus avoiding double drying.

In the paper manufacturing process, fibers are delivered to paper-forming screens on Fourdrinier machines, using a water solution at about .5 percent consistency (i.e., 1 part solids to 200 parts fluids). From the screens or the so-called "wet end" of the machine, the paper moves through a series of suction devices and presses where the water content is partially removed. The paper then moves through driers where heat is applied to reduce final moisture content to about 5 to 10 percent. This is the so-called "dry end" of the paper making machine.

High consistency forming and dry-forming of paper are examples of potential energy saving technologies (see Appendix E, Exhibit II for detailed discussion). Such commercially feasible processes which will allow paper manufacturers to reduce substantially or eliminate water in paper forming would have many advantages. Those areas which are specifically related to energy savings in these processes are:

- High Consistency Forming Process

  --Less power is required to pump the fiber solution or stock.

  --The paper enters the drying section at a significantly lower moisture content thereby reducing the evaporative energy required per ton of output.

- Dry-Forming Process

  --Less power is required to drive the paper making machine because the entire dry end has been substantially reduced in size.

  --The pressing as well as drying requirements are reduced.

Constraints

If both high consistency and dry forming become commercially viable, the chief constraint to the early and widespread adoption of these technologies will be the capital costs of scrapping existing equipment and installing new machines. How improved operating costs, due chiefly to lower levels of energy consumption, will trade off against the investment in existing capital, cannot be accurately quantified.

The additional energy required to operate pollution abatement equipment may override the potential energy savings of all conservation steps. One problem in projecting the energy impact of environmental regulations is that guidelines have only been recently promulgated, and individual companies have not yet had the full opportunity to analyze completely the probable energy requirements. Also, the guidelines are currently being challenged in court.

The National Council for Air and Stream Improvement has estimated that water and air quality standards would require an increase in purchased energy per unit of output of 7 to 11 percent in the paper industry between 1971 and 1983. Furthermore, there are indications that if the 1985 "zero discharge" target is enforced, the energy requirements will be much greater.

In July 1973, the American Paper Institute retained a consultant to evaluate the impact of several designated water pollution abatement targets. With regard to zero discharge, the consultant found that if current technology which might be borrowed from the sea water desalinization program were in fact capable of removing all added constituents of paper in the industry's effluents, additional energy requirements might total at least 45 percent of the 1972 industry purchases of fuel and power. This is approximately the equivalent of 95 million additional barrels of fuel oil annually, or 260 thousand barrels per day at 1972 production levels.

ALUMINUM INDUSTRY

The aluminum industry's major use of energy is in the form of electricity required for the electrolytic reduction of aluminum oxide to extract metallic aluminum. The latest and most modern smelters (Hall Process) use about 6.5 kilowatt hours (KWH) per pound of aluminum produced. The present average for the industry is about 8 KWH whereas, in 1940 the average was 12 KWH.

Recently, one aluminum company reported that it had applied for patents on a new electrolytic method of producing primary aluminum. This new process is expected to reduce the electricity required by the most efficient units of the Hall Process (presently used worldwide) by as much as 30 percent, or to about 4.5 KWH per pound.

The new process (see Figure 2) employs alumina--the oxide of aluminum which currently is refined from bauxite ore. Alumina obtained from ores other than bauxite will be equally suitable for the new process. In the smelting process, alumina is combined with chlorine in a reactor unit which chemically converts the oxide to aluminum chloride. The chloride is electrolytically processed in a completely enclosed cell which separates the compound into molten aluminum and chlorine. The latter is continuously recycled back to the reactor in a closed loop. The process uses a system free of undesirable emissions and affords the employee a superior working environment. In addition to requiring less energy, the process is more tolerant of power interruptions than is the Hall Process, and can accept power reductions necessitated during daily periods of peak demand by the public. Total operating costs are expected to be lower and plants can be located on smaller sites with greater location flexibility.

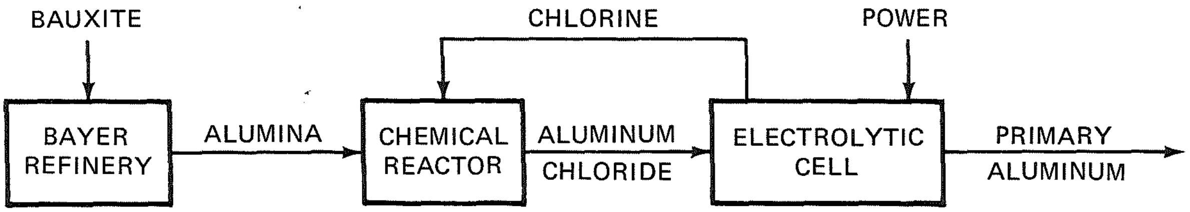

Figure 2. Alcoa Smelting Process.

In the Hall electrolytic process, alumina is dissolved in molten cryolite--a fluoride chemical which has become increasingly scarce and costly. The new process not only disposes of the need for cryolite but also the expense of containing fluoride emissions.

Long-Term Conservation Potential

The first commercial plant using the Alcoa Smelting Process is under construction in Texas. The first unit will have an initial capacity of 30,000 tons per year of primary aluminum and is scheduled to start up in late 1976. Completion of the entire plant presently planned as a 300,000 ton capacity facility is now scheduled for 1981.

While there is great hope for the new process in "grassroots" applications, there will not be any overnight obsolescence of established facilities for smelting aluminum. Further, if capacity is added at existing smelters it would probably be Hall-type equipment.

CEMENT INDUSTRY

In 1971, the U.S. cement industry consumed about 0.6 quadrillion BTU's of energy per year. Individual cement plants used far more energy per ton of cement produced than plants in Japan and Germany:

KILN ENERGY CONSUMPTION
(Million BTU's per Ton of Cement Produced)

Year	U.S.	Japan	Germany
1971	6.113	3.800	3.260
1973	5.987	3.890	3.620

Two important factors have differentiated the U.S. cement industry from cement industries in other countries: the United States has had comparatively expensive labor and enjoyed abundant and inexpensive fuel. As a result, the U.S. cement producer has continuously reduced the amount of labor required in the production of cement. Since 1945, labor productivity for U.S. cement manufacturing has increased from .52 tons per man hour to the present 1.3 tons per man hour. In the same period, unit energy consumption has decreased from 8.05 million BTU's per ton to 5.99 million BTU's per ton. The gain in energy productivity, although significant, is less than one-half of the gain shown in labor productivity. The situation has changed as a result of the higher costs of energy.

The difference in efficiency of the new plants in Japan and Germany results from use of dry processes which mix the raw material dry before calcining *versus* the older U.S. plants which wet-mix the ingredients before calcining. This is the major influence on the amount of energy consumed in various countries.

The short-term steps that the industry has been taking to conserve energy have included the installation of chain sections, minor kiln alterations, insulating refractories, dewatering slurry by additives, adding heat exchange, improved quarrying and material handling operations, more efficient distribution methods, the adjustment of raw materials balance, and utilization of waste heat for drying. The full impact of the higher energy costs will stimulate educational programs for industry employees and the employment of energy-saving practices in a plant, such as improving the seals on a kiln.

A wholesale switch of all wet and obsolete dry plants to the preheater system could have reduced the total energy consumption in 1973 by about 14 percent. The technology exists for most of the transformation but the cost would be large in comparison with the small size of the industry. About one-third of the industry change-over from wet to dry can be made by 1978 for about a 5 percent gain. By employing the short-term steps listed and the changeover recommended, a total energy reduction of 10 percent for Phase I is anticipated.

Long-Term Conservation Potential

A number of innovations are being developed by the cement industry to reduce energy consumption. Since foreign competitors have used higher cost energy in the past, a number of these new processes and equipment designs have been implemented by foreign firms.

The newest such process is a modified suspension pre-heater (SP) kiln system. In this system, about 50 percent of the fuel is burned in the stationary portion of the pyroprocessing equipment (the pre-calciner) as compared to 100 percent in the rotating kiln. The principal advantage of this type of equipment is significantly higher productivity. The energy-saving capability is about 80 thousand BTU's per ton.

Further, the modified SP system can be used to burn kerogenic raw materials (those containing organic matter) as fuel which cannot be burned in the standard SP system. A third distinct advantage of a pre-calciner is its ability to reduce heat waste when it becomes necessary to by-pass gases in order to remove the volatile salts that plug the ordinary SP kiln system. For example, a 20 percent by-pass on an ordinary SP kiln would expend 350 thousand BTU's per ton of clinker, but only about 150 thousand BTU's per ton would be wasted in a similar by-pass in a pre-calciner system.

Other methods offering potential for energy conservation are:

- Grinding of many types of raw materials in the newer roller mills has a potential for saving an average of 15 percent or more of the energy normally required for raw grinding. Use of roller mills is not feasible for all sources of raw materials particularly those with high silica content. Roller mills can also use waste kiln heat to remove up to 8 percent moisture from the raw materials. There is some optimism that after further research, the roller mill may be used to save up to 25 percent of the energy now required for finish grinding of cement.

- Improved burners using the Linde or Lurgi swirl design save energy by reducing excess air requirements. Submerged burners and fluid bed processing also add efficiency to the cement producing system by reducing radiant energy losses.

Possibilities of supplementing the traditional fuels (coal, oil, gas) with auxiliary energy sources are being explored. Potential fuels that may be useful are oil shales, coal shales, sawdust, petroleum coke, shredded refuse, and waste motor oils. Use of such fuels depends on availability of sufficient quantities, location, available equipment, and in some cases, additional research.

- A new energy conserving pollution control device shows promise as heat recovery equipment from kiln flue gases.

Constraints

As a prerequisite for any meaningful reduction in energy consumption in the cement industry, it is necessary that the present financial and technological constraints be resolved. Some constraints are:

- Insufficient capital and inadequate return-on-investment to make major long-term fuel conservation measures feasible
- Stringent environmental standards
- Restrictive alkali specifications.

Due to antiquated facilities, major gains in U.S. energy efficiency are possible provided that the financial constraints presently facing the cement industry are resolved.

Cement manufacturing is highly capital intensive and replacement of existing plants to adopt new technology will be very expensive. Nevertheless, over the next several years the U.S. cement industry will phase-in new, more energy-efficient technology. Because of the amount of the capital required in relation to the cement industry's financial resources, the rate at which the new technology will be adopted is expected to be slow but continuous. As the newer and larger production facilities are built, the cement industry is expected to realize lower unit fuel costs.

INDUSTRIAL BOILERS

Because of the present environmental legislation, many higher sulfur coals cannot be burned in industrial boilers unless very expensive sulfur dioxide (SO_2) removal systems are installed to condition existing flue gases. A promising new combustion method that can work for all kinds of coals regardless of sulfur content is the fluidized bed combustion process. This process has been in the pilot-plant stage for nearly two years and is a low temperature combustion process that uses limestone in a slowly moving bed. Much of the ash and sulfur is removed in the bed, vastly reducing the need for costly stack gas conditioning systems. However, the process which has excellent potential for smaller industrial boilers is still in the early developmental stages.

Four important characteristics distinguish fluidized-bed combustion from that which takes place in coal-fired boilers now on the market:

- The coal may be burned within a fluidized-bed very rapidly and in a limited space. Compared with existing technology, the increase in the volumetric heat release rate is on the order of 10 to 1.
- The heat is transferred to the boiler tubes rapidly and more significantly uniformly. Compared with existing technology, the improvement in the average heat flux ranges between 3 and 6.
- A closely spaced arrangement of the boiler tubes is practical thereby making the fluidized-bed boiler compact. Compared with existing technology, the ratio "heat transfer surface per unit heat release volume" may be increased by a factor of 10.
- A fluidized-bed provides a highly reactive zone in which combustion may be carried out very rapidly. Operating temperature reductions of as much as 1,000°F are feasible.

Long-Term Conservation Potential

These four characteristics make the following advantageous features possible in fluidized-bed boilers:

- Equipment cost reduction of 50 percent from existing technology systems.
- Reduction in air pollution caused by oxides of sulfur or nitrogen at lower cost than any available alternative.
- Increase in thermal efficiency so that more energy might be obtained from each pound of coal.
- Ability to burn coals having low ash fusion temperatures without creating slagging problems.
- Ability to burn high ash fuels without incurring substantially higher operating costs.

Fluidized-bed combustion of coal is practical and large fluidized-bed boilers can be assembled in factories at a relatively low cost. The cost reduction arises not only from the characteristics of fluidized-bed combustion but more importantly from the economies made possible by manufacturing large-capacity packaged boilers. A packaged unit is one that is essentially shop fabricated and shipped to the purchaser's site. Previously, the advantages of shop fabrication have never been applied to coal-fired boilers above 50,000 pounds per hour capacity. The state of the art in packaging has progressed to the point where it is less costly to purchase and install two packaged units than a single unit requiring assembly in the field.

Constraints

The following technical constraints apply to boiler utilization:

- Environmental constraints on the disposal of limestone-ash.
- Technical problems of maintaining the fluidized-bed and controlling formation of the limestone-ash.
- Material of construction to ensure long operating periods with acceptable operating factors.

Chapter Two

RESIDENTIAL/COMMERCIAL

For purposes of this study, the residential and commercial sectors were separated and examined individually. The residential sector is defined as consisting of single family dwellings, housing units for two families, and mobile homes. The commercial sector is defined as consisting of all multi-family housing for three or more families as well as public and other commercial buildings. In this chapter, the split between residential and commercial energy consumption differs from that employed in the Past Trends-Continue case (see "Parameters of Study," Summary), in that the energy consumed in dwelling units of three or more families is allocated to the commercial rather than the residential sector. This reallocation is made due to the similarity in construction between such multi-family units and commercial units as opposed to residential structures. Therefore, energy saving possibilities for apartments are better examined in the commercial portion of this chapter.

The following discussions of the residential and commercial sectors are primarily examinations of technological improvements in equipment which may increase the efficiency of energy utilization within each area. Building components or systems which could reduce demand for depletable energy resources through use of nondepletable resources are also examined.

Geothermal and solar (including winds and tides) are examples of nondepletable energy sources. Systems utilizing these sources will likely offer significant long-term potential for conservation of depletable energy resources. However, it appears that the major impact of these systems on the Nation's energy posture will be in the period beyond 1985 and into the next century.

Technologies presently exist for on-site direct utilization of some of these energy sources. Some examples are heat pumps and solar heating/cooling systems. The application of these systems is limited geographically by the degree of temperature variation and continuity of solar energy. Therefore, in many areas, such systems must be augmented by back-up systems utilizing depletable energy resources. This duplication of systems within the structure increases initial consumer investment costs. In the future, as larger numbers of such duplicate systems are placed in operation, savings in operational costs may not be correlated to savings in depletable resources. For example, the utilization of heat pumps or solar heating to conserve energy might still require that the consumer have a stand-by heating system. The energy supplier would have to maintain increased capacity. Therefore, consumer costs in the aggregate might well increase. This would not necessarily result in all sections of the Nation as the suppliers in many of the areas that would use solar systems have their capacity sized for seasonal peaks and have excess capacity.

Presently, the consumer must base his purchase decision on the market value of the equipment, the cost of the energy being augmented, and the climatic conditions of the area. If solar equipment costs are reduced through innovations in manufacturing methods and/or energy costs continue to escalate, at some point the investment will become viable. The timing of the impact of new technologies in this area is dependent on research and development (R&D), and the investment incentives that exist.

RESIDENTIAL

For the Phase II period (1979-1985), energy savings potentials in the residential market are divided into three areas:

- Existing housing
- New construction--"add-on" and "replacement" housing sectors
- Residential equipment and appliances.

The techniques for improving residential energy efficiencies in the existing housing and new construction markets were examined in the Phase I report.* Therefore, this discussion is primarily an examination of residential equipment and appliance technologies which offer potentials for energy conservation.

It is important to emphasize that energy savings in the new construction market will be affected through upgrading building standards so that they will be more energy efficient than the standards employed today. However, it must be recognized that today's standards are greatly improved over previous standards and codes. In fact various studies made by the National Association of Home Builders confirm that today's standards are approximately 60 percent more efficient than those utilized 40 to 60 years ago.

Future standards, such as those outlined in Phase I which could be effective by 1978, could be about 30 percent more efficient than present day standards. This point is extremely important since it is projected that during the decade of the 1980's for every two residential units built, one will be used to replace a demolished unit. Thus, a very inefficient unit can be replaced by an extremely efficient one and consequently large savings can accrue.

Residential Market Description

Table 4 presents the 1973, 1978, and 1985 estimated total residential housing base and the 1974-1978 and 1979-1985 add-ons, according to housing type (single family, two family, and mobile

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* National Petroleum Council, *Potential for Energy Conservation in the United States: 1974-1978*, Washington, D.C.: 1974, pp. 49-55.

TABLE 4

EFFECT OF NEW CONSTRUCTION
ON TOTAL HOUSING MIX IN THE RESIDENTIAL MARKET

	Single Family*		Two Family		Mobile Homes		Total	
	Units	Percent	Units	Percent	Units	Percent	Units	Percent
1973 Estimated Market	48,717,900	85.0	5,538,400	9.7	3,023,700	5.3	57,280,000	100.0
1974-1978 Add-Ons†	3,480,600	54.5	836,600	13.1	2,069,200	32.4	6,386,400	100.0
1978 Estimated Market	52,198,500	82.0	6,375,000	10.0	5,092,900	8.0	63,666,400	100.0
1979-1985 Add-Ons†	4,979,300	59.7	884,100	10.6	2,477,100	29.7	8,340,500	100.0
1985 Estimated Market	57,177,800	79.4	7,259,100	10.1	7,570,000	10.5	72,006,900	100.0

Note: Adjusted to conform with Chapter Two definition of "residential market."

* Totals vary from Table 2 due to source difference employed to provide data on two family and mobile home units.

† Demolitions factored out.

Source: National Association of Home Builders, *Housing Requirements in the 1970's and 1980's*, Washington, D.C., January 1974, Table 3-21.

homes). An analysis of the data indicates that in the future, single family units will provide for a smaller percentage of the Nation's housing requirements. Due to the large existing housing base, a total change in housing mix will evolve slowly. Therefore, the single family unit will remain the major source for potential reductions in residential energy consumption until 1985 and beyond.

Residential Energy Consumption

The Past Trends-Continue residential demand projections were adjusted on Table 5 to arrive at equivalent figures for this chapter's definition of the residential sector. The "total residential energy demand" column includes conversion losses from the generation of electricity. On Table 6 these figures from 1972-1985 are depicted by type of energy (fossil or electricity). Under the Past Trends-Continue case projections, total residential energy requirements between 1979-1985 were projected to increase at an average annual rate of 3.5 percent per year. For this same period and under the same case, fossil fuel demand would increase by an average annual rate of 1.3 percent per year while electricity demand would increase at a rate of 6.2 percent. Thus by 1985, total end-use energy requirements in the residential market are projected to be 12.043 quadrillion BTU's. Of this amount, 8.694 quadrillion BTU's (72 percent) will be derived from fossil fuels with the remainder (28 percent) being supplied in the form of electricity.

Due to the accelerated growth in the consumption of electricity, electric conversion losses (BTU's lost in the conversion of a fossil fuel to electricity) would increase by an average of 5.8 percent per year. By 1985, conversion losses (7.9 quadrillion BTU's) would be equivalent to 66 percent of all the BTU's (12.016 quadrillion BTU's) consumed by the residential market in 1972. This finding is a result of the fact that electricity traditionally has had an energy efficiency of 30 percent (see Table 7). Gas and oil have comparable numbers of 93 and 88 percent, respectively. By multiplying these ratios by the estimated utilization efficiency, the total efficiencies of the various fuels for different residential applications have been computed.

Areas of Conservation Potential

In the 1974-1978 period, the bulk of energy savings potential will be derived from approaches applied to the existing housing market: (1) living habits/life-styles; (2) upgrading thermal performance levels; and (3) heating and air-conditioning maintenance. Energy savings potential due to improved building standards for both add-on and replacement housing will be about one-half of the potential savings for existing housing.

However, in the 1979-1985 period, the relative importance of the possible savings areas will begin to shift. New construction, both add-on and replacement housing, will offer the largest potential for conservation. The majority of this potential is due

TABLE 5

COMPUTATION OF RESIDENTIAL ENERGY DEMAND
(Quadrillion BTU's)

Residential Consumption*			Electric Conversion Allocated to Residential Sector*		Adjustment Factor (Percent)†		Total Residential Energy Demand
1972	10.5	+	(33.8% x 13.1) = 4.4	x	80.7	=	12.0
1978	12.8	+	(34.4% x 19.8) = 6.8	x	79.1	=	15.5
1980	13.6	+	(34.4% x 22.7) = 7.8	x	78.1	=	16.7
1985	15.5	+	(33.7% x 30.1) = 10.1	x	77.7	=	19.9

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* Past Trends-Continue case, Table 1, "Parameters of Study" section.

† Percent of Past Trends-Continue residential demand considered as total residential sector demand as defined in Chapter Two, remainder allocated to commercial sector.

TABLE 6

GROWTH IN RESIDENTIAL ENERGY CONSUMPTION
(Quadrillion BTU's)

Energy	1972	1978*	1980*	1985*
Fossil Fuel	6.989	7.885	8.075	8.694
Electricity	1.484	2.239	2.546	3.349
Subtotal	8.473	10.124	10.621	12.043
Allocated Electric Conversion Losses	3.543	5.395	6.100	7.879
Total	12.016	15.519	16.721	19.922

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* Projected figures based on Table 1, "Parameters of Study" section. (Adjusted to conform with Chapter Two definition of residential structures.)

to the possible improvements in future building standards over current standards. Even though an equal number of replacement and add-on housing starts are projected for the Phase II period, replacements should offer a larger conservation potential since they will be substituted for the older, more inefficient units being demolished. Existing construction will continue to be a significant base for potential savings during this period. Long-term residential equipment savings are expected to offer some moderate possibilities for reduction in energy demand.

Success in conserving energy by the various actions that have been examined will depend on specific incentives. While any of the approaches could be mandated, a successful conservation program will more likely rely on voluntary compliance by the consumer. The most effective incentive to gain voluntary acceptance of the conservation theme is the economic one. Some additional response to either patriotic or social considerations could be significant in the behavior of residents. These will usually be tempered by cost considerations which could be supplemented by government action. The effects of cost considerations differ for each category that consumes energy.

Regardless of the degree to which these influences are voluntary or mandatory, the success of a conservation program particularly in the residential sector depends almost entirely on credible and continuing communications programs designed to build and maintain the public awareness for the need to conserve energy.

TABLE 7

HISTORICAL ENERGY EFFICIENCY OF FUELS IN RESIDENTIAL APPLICATIONS
(Percent)

Type of Application	Energy System Efficiency (Column 1)	Estimate Utilization Efficiency (Column 2)	Total Efficiency (Column 1 x Column 2)
Home Heating			
Gas	93	66	61
Electric (Resistance Only)	30	98	29
Oil	88	66	58
Water Heating			
Gas	93	65	60
Electric	30	91	27
Oil	88	60	53
Cooking			
Gas	93	40	37
Electric	30	75	23
Clothes Drying			
Gas	93	65	60
Electric	30	65	20
Air Conditioning			
Gas	93	35	33
Electric	30	205*	62

Source: "Conservation of Energy" a National Fuel and Energy Policy Study: Proposed by Committee of Interior and Insular Affairs, U.S. Senate Resolution #45; EPA 650/2-74-003, "A Study of Air Pollutant Emissions From Residential Heating Systems," Appendix C, Parts 1-3.

* Coefficient of performance.

The Phase I study recommended that an extensive and coordinated communications network involving both industry and government be developed. Such programs have been established and should be encouraged in the future. A detailed discussion of conservation potentials for the existing housing market, new construction, and equipment and appliances is presented in the following sections.

Conservation in the Existing Housing Market

Conservation in this sector is dependent on three major variables: changing life-styles, upgrading thermal performance levels, and maintenance of heating, ventilating, and air-conditioning systems (HVAC).

- Conservation through changes in life-style includes items such as home heat thermostat settings and efficient use of appliances. Techniques such as these will depend on behavior of individual residents and must, for all practical purposes, be considered voluntary. Operational cost savings due to a reduction in energy consumption should provide the highest motivation.

  There may be some response to patriotic and/or social appeals such as the desire to support the aims of the country, fear of dependency on other countries, the desire to protect our finite natural resources, or the desire to conserve in general. Since these appeals could also result in cost savings, there should be no conflict. Well-planned, coordinated, and creative national programs should be effective in obtaining voluntary response. The sheer size and number of units in the residential market would make mandatory controls difficult to enforce.

- Conservation through the upgrading of thermal performance levels includes items such as adding ceiling insulation, storm windows and doors (permanent or plastic film), and weatherstripping and/or caulking. These actions, while voluntary, could involve significant initial cost. Thus, the key monetary message to the consumer should be actual dollar savings resulting from reduced operational costs. Tax relief legislation to assist the consumer could stimulate the desired action. Government agencies could also encourage energy conservation measures by offering and/or guaranteeing low interest loans.

- Motivations to conserve energy through equipment maintenance actions should be encouraged, although this may involve additional cost to the homeowner.

Influencing either the owner or the resident of rental property to spend money to save energy is not easy, short of compulsory improvements to meet new or revised building codes. Tax relief legislation on rental units may be effective in motivating owners or residents to upgrade their structures.

Conservation Through New Construction

Conservation through new construction features includes such items as optimizing house shape, reducing window area, and installing additional insulation. The effectiveness of these conservation techniques depends on behavior of both the builder and the buyer.

Expenditures on new homes to reduce operating costs could appeal to the owner even though higher first costs would be involved. The builder traditionally resists higher construction costs unless the features have universal appeal or are required by the owner or some other agency. Higher costs may put the builder at a competitive disadvantage.

Some other measures which could influence energy conservation in this area are:

- Building codes which have specific performance-oriented standards for all residential construction.
- Life-cycle costs (first cost plus lifetime operating costs) for the buyer. This information could be used in considering the purchaser's or builder's qualification for loans.
- Education and incentives to encourage additional expenditures on energy conservation features.
- Encouragement of architects by clients to design for energy optimization.

Conservation Through New Equipment and Appliances

As in the new construction area, motivation for energy conservation could be promoted by supplying the purchaser with information which could include life-cycle costs and instructions for efficient operation of equipment. This would aid the consumer or builder in the selection process. Tax relief or some other incentive system could be offered to industries that develop energy-efficient products. This incentive could also be offered to the buyer of such appliances.

Equipment and appliance technology which might be employed by 1985 and which could offer significant reductions in residential energy consumption is considered below. This technology involves components and systems that are in various stages of development:

- Those commercialized but not in significant distribution
- Those ready for or close to commercialization
- Those in laboratory development
- Those in the conceptual state of development.

The technologies which are in the laboratory or conceptual state of development will have little, if any, impact on consumption in the period until 1985 even if perfected in the near future. At the same time, the impact of technologies that are commercially feasible may be diluted by production bottlenecks and capital fund shortages.

Tables 8-11 list equipment which could enhance the conservation of energy and accompany the discussions of these components and systems. These tables also show the prospective economic value to the consumer of each technological development on a four-point scale of excellent, good, fair, or poor.

Heat Pump Description

The heat pump is a system which is designed to transfer heat from a colder to hotter location. The heat from the colder location must be upgraded (i.e., temperature increased in the system to effect the transfer). Properly designed systems can be used for both heating and cooling.

In the heating cycle, heat is absorbed from an outside source by a suitable refrigerant. This heat is upgraded in the system by compression of the refrigerant or by other methods. The upgraded heat is then transmitted to the areas to be heated through a condenser exchanger arrangement and the cycle is repeated. The refrigeration cycle is the reverse of the heating cycle.

The effectiveness of the system depends on the system design and the temperature differences of the hot and cold locations involved (i.e., effectiveness decreases with increasing temperature differences). Therefore, the heat pump is not as efficient in colder areas (where temperatures below 20°F are experienced) due to supplemental heating requirements. The primary advantage of the heat pump lies in reducing the fuel needed for heating by utilizing low grade heat energy available in the surrounding environment that could not otherwise be utilized for these purposes.

Types of Heat Pump Systems

Evaluations of various types of heat pump systems are given in Table 8. The following is a discussion of each system.

- *Electric Heat Pump:* Although electrically driven presently available heat pumps are not as efficient as present direct-fired systems, they are more efficient than conventional electric resistance heating in moderate climates. The energy demand reduction of 40 percent associated with the air-to-air electric heat pump refers to the energy saved by its substitution for electric resistance heating. Further development of the water-to-air and water-to-water heat pumps used in conjunction with solar energy and liquid heat storage facilities could reduce usage associated with resistance heating by 60 percent. The applicability of the last

TABLE 8

EVALUATION OF HEAT PUMPS

Component Product or System	Stage of Development	Potential Demand Reduction on Like Energy Sources	Cost/Efficiency Evaluation
Electric Heat Pump (Air-to-Air System)	Production Capacity	40%*	Good-Excellent
Electric Heat Pump (Water-to-Air; Water-to-Water Systems)	Minor Development	60%*	Fair
Gas Heat Pump (Air-to-Air System)	Laboratory (3-5 Years)	50%†	Good-Excellent
Oil Heat Pump	Recommended Development	50%†	Good-Excellent

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* Based on reduction from electrical resistance heating.

† Based on reduction from conventional gas or oil heating.

two systems will vary geographically depending on the local availability of water and the amount of solar radiation received. Viable installations are not assumed feasible until after 1985.

- *Gas Heat Pump:* Utilizing available technology, energy savings potentials as high as 50 percent are estimated for gas heat pumps when compared with conventional gas heating systems. Current hardware aimed at technological effectiveness may be commercialized by 1979-1980.

- *Oil Heat Pump:* Although industry does not have an oil heat pump at present, it is thought that emphasis will be placed on the development of a central type unit, as opposed to the window type associated with the electric heat pump concept.

Heating Systems

Evaluations of potential heating systems are given in Table 9. The following is a discussion of each component.

- *Heat Exchangers:* The heat exchangers now incorporated in heating equipment have been designed and built for low first cost. The heating equipment manufacturer produces mainly

TABLE 9

EVALUATION OF HEATING SYSTEMS

Component Product or System	Stage of Development	Potential Energy Demand Reduction	Cost/Efficiency Evaluation
Heat Exchangers (Component)	Limited Production	10-15%	Good-Excellent
Pilot Thermo-generators (Component)	Limited Production	5-10%	Good
Automatic Dampers (Component)	Limited Production	3-4%	Good
Modulating Burners (Component)	Limited Production	10%	Good
Full Control Combustion Air (System)	Advance Field Test	10-27%	Good-Excellent
Blue Flame Burner (Component)	Limited Production	4%	Fair-Good
Stack Mounted Dampers (Component)	Limited Production	5-10%	Good

to compete in the new construction market. This market is extremely competitive and oriented toward a low first cost consideration. The present equipment is rated from 65 to 75 percent efficient. A unit utilizing new heat transfer technology is presently available that has an efficiency approaching 85 percent. The technology exists for the production of units one-fourth the size of and 10 to 15 percent more efficient than conventional units. However, high first cost remains a deterrent to its utilization.

- *Automatic Dampers, Modulating Burners, Pilot Thermogenertors:* These components are all known energy savers in the 3 to 10 percent category. All of these are in limited production as they are in limited demand. Most manufacturers do not incorporate these components as features in regular production because they are placed in an uncompetitive first cost position. The high cost of automatic dampers results from the associated safety requirements.

- *Full Control Combustion Air System:* The electric heat pump now in production when coupled with a conventional natural gas, propane or oil furnace could enable a 10 to 27 percent energy savings over the use of an electric air conditioning and fossil fuel heating system. This can be accomplished when the heat pump is utilized in its feasible geographical range as both a cooling and heating unit, and a fossil fuel heating system (not electric strip) is used for back-up heating.

- *Blue Flame Burner:* The blue flame burner is designed to function at high efficiency and with low emissions. The burner operates with a distinct blue flame and the flue gases are recycled through the heat exchangers. Claims of slightly higher efficiencies than those of conventionally designed burners are made for this component.

- *Automatic Stack Mounted Dampers:* The automatic damper can be integrated into existing oil-fired systems. There is no need to replace or modify existing burners since the damper does not change the normal operation of an oil-fired system. The damper is installed in the stack between the heat plant and the outside exhaust opening. It is electrically connected in series with the system's control unit which prevents the oil burner from operating while the damper is in a closed position. Questions involving safety standards have limited the installation of this component.

Appliances

Evaluations of appliances offering potential efficiency improvements are given in Table 10. The following is a discussion of each component or system.

- *Compressors:* Compressor efficiency may be increased in the range of 10 percent by incorporating more efficient design applications. Compressor efficiency offers great potential when included in the refrigeration unit where the total system efficiency may be calculated.

- *Motors:* Motors offer little increased energy efficiency within the confines of current technological developments. Assumed increased energy efficiencies of 5 percent may be overrated in the current or near future design of electric motors.

- *Refrigerator/Freezer:* Efficiency increases achieved through the design of compressors and in other thermal treatment offer system efficiencies ranging from 15 to 25 percent.

- *Home Lighting:* Lighting efficiencies are achievable not only through design but also through the application of more efficient existing lighting sources (i.e., utilizing fluorescent instead of incandescent lights). Efficiencies may be achieved in lighting through better methods of luminaire design and thermal protection of the ballast.

TABLE 10

EVALUATION OF APPLIANCES

System	Stage of Development	Potential Energy Demand Reduction	Cost/Efficiency Evaluation
Compressors (Component)	Full Production	10%	Excellent
Motors (Component)	Full Production	5%	Good
Refrigeration/ Freezer (System)	Limited Production	15%	Excellent
Home Lighting (System)	Limited Production	15%	Excellent
Water Heaters (System)	Full Production	15%	Excellent
Dishwashers (System)	Full Production	5%	Good
Gas Range Convection Oven (Component)	Limited Production	37%	Excellent
Solar Water Heating (System)	Limited Production	10-20%	Poor-Good*

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* Related to geographic location.

- *Water Heaters:* Water heating systems which account for the second largest item of energy consumption in a home required emphasis on design for thermal efficiency. This includes improvements in heat exchange and insulation methods. Such changes may improve efficiency by 15 percent.

- *Dishwashers:* Dishwashing appliances offer little opportunity for improved energy efficiencies. However, if considered as part of a system which includes water heating and water utilization, some energy savings potential is offered.

- *Gas Range Convection Oven:* A gas convection oven is currently being field tested and will be on the market during the latter part of 1975. This unit can reduce cooking time of some foods by 60 percent, and will reduce energy requirements up to 37 percent.

- *Solar Water Heating:* Technology is currently available to utilize solar energy for domestic water heating. Also, some of the solar home heating systems being tested include domestic water heating as well as space heating. Solar domestic water heating systems have been used in certain areas of the southern United States and in other parts of the world where conventional energy sources have not been readily available. These systems can reduce depletable energy resource requirements by 10 to 20 percent.

Solar Energy Systems

Evaluations of potential solar heating and cooling systems are given in Table 11. Efficient, cost-effective and direct use of solar energy, an abundant and nondepletable natural resource, has been a continuing endeavor over the centuries. Efforts are being accelerated in the United States to utilize this energy resource directly in line with energy economies and environmental problems. Almost every major university now operates a solar energy laboratory. The number of specialists now manufacturing and marketing components is growing (14 in the United States as of June 1974). The Federal Government recently approved $60 million for solar research over a five year period in addition to $53 million already allocated for fiscal year 1975.

TABLE 11

EVALUATION OF SOLAR HEATING AND COOLING SYSTEMS

System	Stage of Development	Potential Energy Demand Reduction on Conventional Energy Sources	Cost/Efficiency Evaluation*
Heating System (Water-to-Water: Water-to-Air)	Limited Production	30%-60%	Poor-Good
Heating System (Air-to-Air)	Limited Production	20%-60%	Poor-Fair
Heating/Cooling System (Water-to-Air)	Benchmodel (2 Years)	30%-75%	Poor-Good
Heating/Cooling Limited Electrical System (Water-to-Air)	Prototype	30%-75%	Poor-Good

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* Related to geographic location.

The National Science Foundation and the Rand Corporation published *Solar Heating and Cooling of Buildings; Phase Zero Studies* and presented it to the International Solar Energy Society in Colorado, August 20-23, 1974. The major points include:

- Solar energy for heating, cooling, and domestic hot water is technically feasible. It is economically competitive with electric-resistance heating today; improvements are required before solar systems will be competitive with gas and oil.
- In spite of the obstacles, solar systems manufacturing will be at an annual rate of $1 billion to $15 billion by the year 2000. New construction will be the principal market.
- Proof-of-concept experiments are a necessary step in the process of the program before widespread demonstration.
- Various types of incentives will be needed to accelerate widespread use.

Solar energy use in individual structures will have a significant impact on energy consumption only in the long run (as with central station technology, noted in the following). Reasonable estimates for 1985 put savings from solar energy at less than one-fourth of 1 percent of total national energy requirements.

Abstracts by Oak Ridge National Laboratory (ORNL) from papers dealing with solar energy indicate a wide range of approaches and considerations from central station to homes. The FEA places solar energy, central station technology in the same time frame as the breeder reactor with regard to their being long-range solutions to our energy problems. The National Bureau of Standards (NBS) is currently designing a solar home to test configuration of both the structure and system.

The scientific goal of achieving the best capture ratio effectiveness of solar energy emphasizes the central station concept. This is a long-term approach. Conversely, the short-term approach involves utilization of available technology in an innovative, cost-effective system for the building structure or home. Over the long term, both approaches could provide a new primary or supplementary source of energy. (For further discussion of solar energy see Chapter Four, "Solar Energy" section, and Appendix H, Exhibits IV and V.)

COMMERCIAL

In Phase I, the examination of the commercial sector emphasized measures for reducing energy consumption in existing structures. The Phase II analysis of the commercial sector examines the avenues available for reducing the normal projected increase in energy consumption in the new construction market for the 1979-1985 period. Three influences on this trend are discussed:

- The impact of current techniques that can be applied to new construction, a number of which were suggested for application to existing buildings in Phase I.*
- The effect of new technologies that are becoming available or will be available within the next decade, assuming research continues to be or is fostered.
- Methods for motivating implementation of the influences noted above.

Areas of Conservation Potential

There are three prime areas relative to a building which can affect optimum energy use. They are the building envelope, building systems, and self-imposed actions. The first two can be implemented through objective engineering design, the third involves the human element.

Building Envelope

The design of the outer face of a building and the material used in its construction determine the building's resistance to heat gain or loss which represents a large portion of the structure's energy expenditure. Some factors influencing the thermal efficiency of the building include: glass area, insulation in walls and roofs, exterior solar shading, and building orientation and/or landscaping.

Basic methods of reducing heat loss and gain through building walls were listed in Phase I. When these methods are applied to new construction, the cost is considerably less than when retrofitting existing structures.

Building Systems

Building systems consist of the mechanical and electrical components utilized in a structure for heating, air conditioning, water heating, lighting, and other services. The design of the systems and selection of the mode of operation will greatly influence the energy use within a building. In recent years there has been some effort to reduce the heat loss and gain of commercial buildings, but this effort has been negated by the installation of sophisticated systems designed for comfort with little or no emphasis on efficient utilization of energy. This is the principal reason for the vast increase in energy consumption in buildings constructed in the late 1960's *versus* those constructed in the 1950's. The continued expansion of air conditioning saturation in new buildings has

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* National Petroleum Council, *Potential for Energy Conservation in the United States: 1974-1978*, Washington, D.C.: 1974, pp. 55-60.

also added to total energy usage. Building system components and designs that are available and can effect conservation include the following (see Appendix F, Tables 23 and 24 for calculations pertaining to these items).

Electric Heat Pumps

Although electrically driven heat pumps are not as efficient as direct-fired, fossil fuel systems, they are currently being used to replace electric-resistance heating in new residential construction. The use of electric heat pumps in commercial buildings is not as extensive as in the residential market; however, their substitution for resistance heating can potentially reduce the electric heat energy usage by approximately 40 percent. The commercial systems are more complex than the prefabricated residential type units, but can readily be incorporated into the heating, ventilating, and air-conditioning system.

System Design

The design of systems to effect energy conservation is a vast subject and cannot be discussed fully within the limits of this report. Potential savings of 5 to 30 percent resulting from the application of this technique are conservative and accrue as a result of the following general approaches:

- Eliminate simultaneous heating and cooling of a room or zone
- Reduce heating and cooling capacities when load is reduced without wasting energy
- Design systems to operate at or near optimum efficiency with reduced building loads
- Cool with outside air whenever possible
- Select equipment for efficient operation
- Select light levels and sources to reduce energy consumption.

Higher Electric Efficiency Ratings (EER)

Improved air conditioning compressor EER can reduce energy consumption during the cooling cycle in a building by more than 20 percent. This equipment is available at a slightly higher first cost.

Heat Reclaim from Refrigeration

Supermarkets can utilize a system design which takes advantage of the heat from the low temperature refrigeration compressors for water heating and space heating. This same concept can be used in other commercial buildings for water heating during the cooling seasons.

More Efficient Light Fixtures

Eight-foot fluorescent tubes are now available which emit the same level of light at a cost of 60 watts *versus* the standard 80 watts.

Self-Imposed Actions

Self-imposed actions include temperature control within the building, mode of equipment operation, and in many instances, the extent of the maintenance expenditures. Savings from reducing internal temperatures during occupied hours, increasing temperatures during cooling cycles, and night setback of thermostats during unoccupied hours and weekends were estimated in Phase I.

Potential savings during the heating season can represent a 35 percent reduction in some buildings. Cooling requirement reductions can provide another 7 to 10 percent. Hospitals and nursing homes are not likely candidates for this approach to conservation. Twenty percent has been selected as the average savings which can be realized by this method. It is a conservative figure, if it is assumed that the measures will be fully employed.

Chronology of Technological Advances

The following is a synopsis of alternatives for energy conservation listed according to their degree of technological development. This is provided to give some conception of what industry has done and is doing through research to improve use of energy resources. Some presently available technology has gone unused due to low energy costs. This condition is changing and this, along with improved building standards will renew the design industry's interest in them.

Available Technology

- Use electric driven heat pumps in place of electric-resistance heating to reduce consumption of electric energy.
- Use controlled combustion for fossil fuel equipment to increase unit efficiency and reduce consumption of fossil fuels.
- Use reflective glass to reduce solar heat gain by 50 percent over standard glass and 25 percent over tinted glass and to reduce electricity consumption during the cooling cycle.

- Use zone control systems to reduce overheat in nonuniform heating and cooling situations thereby reducing fossil fuel and electric energy consumption.
- Employ proper testing, adjusting, and balancing (TAB) of heating and air conditioning systems to ensure that design specifications are met.
- Improve efficiency of appliances to reduce electric and fossil energy consumption in apartments. (Predictions of a 5 percent potential reduction have been made.)
- Use heat exchangers to reclaim heat from drain water to reduce electric and fossil fuel consumption in commercial buildings and apartments.
- Use geothermal energy where available and economically feasible for central heating and cooling complexes.
- Use energy from solid wastes in central heating and cooling complexes.
- Reclaim heat from food refrigeration compressors to reduce space heating and water heating energy requirements.
- Use air conditioning compressors with highest electrical efficiency ratings (EER) to reduce electric energy consumption.
- Reclaim energy from exhaust air in commercial buildings to reduce heating and cooling energy requirements.
- Use high efficiency vented fluorescent fixtures to reduce electric energy consumption.

Technology Under Development (For 1979-1985)

- Develop a heat actuated heat pump to reduce fossil fuel consumption.
- Improve thermal characteristics of clothing fabrics that are suitable for cold water washing.
- Improve efficiency of refrigerants for air conditioning and refrigeration systems.
- Improve components for total energy systems including absorption cooling equipment.

Future Technology (After 1985)

- Employ direct on-site utilization of solar energy where geographically feasible.

- Employ solar photovoltaic conversion systems where geographically feasible.
- Employ wind powered on-site electric generation where geographically feasible.

Potential Technological and Institutional Constraints

- Lack of investment incentives (first costs *versus* life-cycle costs) and availability of capital.
- Lack of performance oriented building codes.
- Availability of technical manpower, designers, engineers, etc.
- Lack of educational programs aimed at conservation needs.

Calculation of Conservation Potential

Energy savings potentials for the Phase II period have been calculated to indicate their relative degree of impact and are shown in detail in Appendix F. It is not realistic to assume that the full impact of all factors necessary to effect these reductions will occur. It is beyond the scope of this report to consider all parameters which would affect achievable overall energy savings; therefore, no accumulative quantification of savings is made. Total potential impact can be reached only if all commercial construction during the Phase II period were designed and built to utilize materials and techniques for the specific purpose of energy conservation.

Implementation of Conservation Measures

In the Phase I report, motivating influences for the application of energy conserving methods in existing construction were discussed. Many of these suggestions also apply to the new construction market. In practice, the means of motivation for the new construction market is more easily applied, than in the case of retrofitting existing structures.

Factors influencing the degree of conservation achieved are the building owners, designers, and regulatory bodies. The building owner is historically and objectively interested in an attractive structure at the lowest capital investment, since investments are made to produce returns. The designer primarily attempts to provide an aesthetically pleasing building, hopefully architecturally singular and within budget limitations. The engineer is charged with making the structure comfortably habitable during varying external conditions, yet within budget restrictions. In so doing, he must also meet certain minimum building standards established by regulatory bodies. These are usually and historically related to safety, health, and welfare.

The limiting factor in achieving greater energy conservation often is the capital requirement. By increasing the investment, all parties could realize their goals; however, this would not appear practical in today's economy. A more suitable solution would be to exploit the economic trade-off between the alternative levels of initial investment and the corresponding energy savings achievable with appropriate emphasis on energy conservation.

Chapter Three

TRANSPORTATION

The people and the economic structure of the United States have benefitted from the utilization of one of the best transportation systems in the world. The prompt and efficient distribution of industrial and agricultural output has helped to create the highest standard of living in the world today. Since transportation utilizes almost one-quarter of the Nation's total energy requirement, it is a prime area for considering energy conservation strategies.

A large number of transportation energy conservation options and their impacts were assessed for the short term in the Phase I study and were quantified based on a given set of assumptions.* However, the impact of these short-term conservation measures cannot be quantified with any high degree of certainty for the 1979-1985 time frame. Some of the short-term measures are deemed to have long-term impacts, and are included in this study. Any quantification for this time period is done only to delineate the relative degree of impact these measures might have, but are not an attempt to derive absolute savings potentials.

Three methods are available to reduce energy intensity within the transportation sector: technological innovation or progress can improve the efficiency of the individual transportation unit; utilization patterns can be modified to improve efficiencies through higher load factors; and the level of services provided can be reduced.

This chapter encompasses an assessment of technological potential for achieving energy conservation in the transportation sector during the 1979-1985 period. The basic approach is to discuss the efficiencies which could be achieved through technology without reverting to mandated curtailment of services rendered by the transportation sector.

Even though the major portion of the U.S. transportation system is operated by the private sector of the economy, it is also one of the most highly regulated sectors. Federal and state governments have established many departments and agencies to oversee the orderly growth of and to ensure the availability of adequate transportation service throughout the diverse economy. Some policies and regulations set forth by government have a bearing on the amount of fuel consumed in transportation but no attempt will be made to quantify their effects. It should be noted, however, that conflicting governmental policies often exist and some regulations actually necessitate greater usage of energy. Many existing regulations are being re-evaluated by government in light of the need

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* National Petroleum Council, *Potential for Energy Conservation in the United States: 1974-1978*, Washington, D.C.: 1974, pp. 61-91.

for energy conservation. This government re-evaluation should recognize that a coordinated "systems approach" is as necessary in the regulation of transportation as it is in vehicle or engine design.

Most of the savings potentials defined in this study are based on the application of new or existing but unused technology. Some of these potential savings may be achieved as a result of energy costs, while others will require different incentives or disincentives such as new or revised regulations. Whatever the case, the transportation system plays an integral role in the economic structure of the Nation. The economic impact of any change including intermodal shifts imposed on that system must be carefully monitored and balanced with the objectives of energy conservation. While it is recognized that intermodal shifts in the transportation sector may offer potential for energy conservation, detailed analysis of long-term potentials was considered to be beyond the scope of this technological appraisal. Short-term intermodal shifts were discussed in Phase I.

To discuss long-term energy conservation potentials in the transportation sector, the basic modes--highway, airway, railway, waterway, urban public transit, and pipelines--were analyzed separately. The highway mode (see Figure 3) represents about three-fourths of the energy consumed in the entire transportation sector. For this reason, the Phase I report considered the highway mode the most productive area for short-term energy conservation

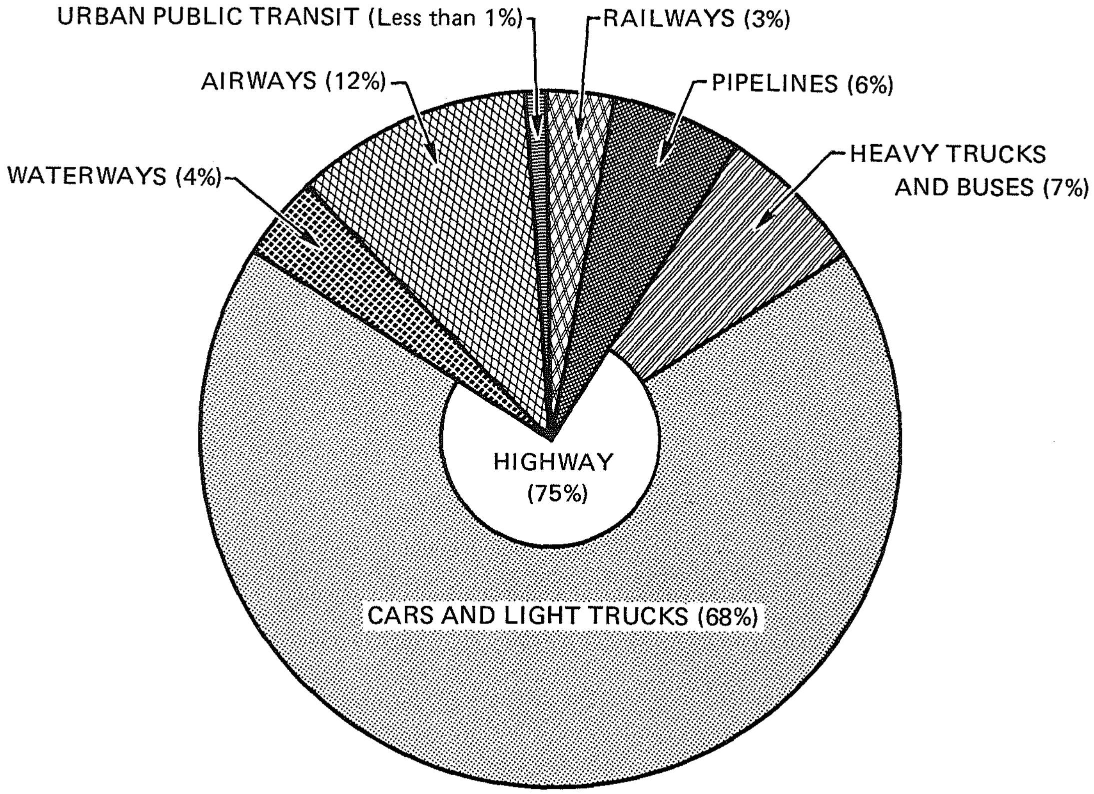

Figure 3. Components of Transportation Energy Consumption--1972.

strategies. Similarly, the long-term (Phase II) technological considerations of this report concentrate on the highway mode.

HIGHWAYS

The highway mode of transportation is utilized for about 88 percent of the Nation's passenger movement, essentially all local shipments of goods, and nearly one-fourth of the inter-city movement of freight. As discussed in Phase I, the highway mode accounts for about 75 percent of the energy used by all forms of transportation, or about 18 percent of the Nation's total energy consumption.

In examining the period beyond 1979, it is uncertain which of the highway measures identified in Phase I will actually be employed. However, the continuation of those strategies that are implemented will result in continued fuel savings during the latter time frame. Once all short-term savings options of modest impact have been implemented, the alternatives for achieving higher levels of conservation are the use of technological innovation or economically disruptive reductions in transportation service. Since reductions in transportation service are not generally advocated, future hopes for energy conservation rest with technological innovation in terms of efficiencies of energy usage. However, it must be recognized that while incentives can be provided to accelerate innovation, technological advancement will not respond per se to mandate. The consumer can be guided by logical and reasonable incentives and the market system of supply and demand will provide the most desirable result.

Passenger Cars and Light Trucks (With Conventional Piston Engines)

Significant improvements in the fuel economy of passenger cars with conventional spark ignited piston engines are anticipated. The individual categories of these potential improvements and the magnitude of effect on fuel economy are depicted on Table 12.

The individual gasoline saving options listed on Table 12 represent maximum theoretical reductions in gasoline consumption. However, several factors will affect the speed and extent of the actual improvement which can be realistically achieved. Among these are:

- The complexity of trade-offs among emissions, driveability, reliability, and mileage which automotive designers must consider, and the availability of finite technological and production resources. These factors limit the degree to which theoretical limits can be approached. If maximum implementation of every potential change were employed, the result would be a car with driveability, reliability or comfort and convenience aspects which might be unacceptable to the motoring public.

- Personal driving characteristics may affect the realization of the full mileage improvement predicted from laboratory

TABLE 12

MAXIMUM THEORETICAL CHANGE IN FUEL CONSUMPTION
1985 *VERSUS* 1974 MODELS
(Percent)

Factors Affecting Fuel Consumption	Change in Fuel Consumption
Reduction in Engine Power Requirements	
Reducing Weights (Same Passenger Capacities)	- 10
Improving Transmission and Axles	- 10
Utilizing Radial Ply Tires	- 3
Reducing Wind Resistance	- 3
Improving Accessory Efficiencies	- 4
Improved Engine Design	- 5
"Economy" Cars	
Smaller Size	- 5 to -10
Lower Power/Weight Ratios	- 6

Note: These percentage improvements are not arithmetically additive.

Assumptions:

- Emission and Safety Standards frozen at 1975/1976 level
- 91 RON Unleaded Gasoline
- 1974 Sales Mix (See Table 15)
- EPA 55/45 Urban-Highway Test Cycle.

tests. "Hot rod" accelerations, wasteful braking maneuvers, and very high-speed driving of a type not represented in the Environmental Protection Agency (EPA) or other recognized test cycles increase gasoline consumption. Actual driving experience of a diverse group of motorists may not correspond to carefully measured tests conducted with professional test drivers.

- Most of the potential options for miles per gallon improvement (such as lock-up transmissions) require the application of new technology. Very few options can be achieved by off-the-shelf application of currently available designs. New technology always requires lead time, a fact which is often underestimated, and involves some uncertainty. Transmission improvements such as tight converters, converter clutches, reduced shift speeds, overdrive, etc., are not compatible with the statutory emission standards scheduled for 1978. Therefore, to attain statutory nitrogen oxide (NO_x) levels, looser transmissions and higher drive ratios will be required on those cars which can be certified.

It is estimated that overall reductions of about 30 percent in gasoline consumption could be achieved by car models sold in the early 1980's as compared to the 46 to 51 percent indicated by the simple addition of the individual gasoline saving options described previously. A 30 percent reduction in gasoline consumption corresponds to an increase of 43 percent in miles per gallon. This reduction in gasoline consumption corresponds with the goal set by the Administration's and automobile industry's voluntary agreement that a 40 percent gasoline reduction, or 20 miles per gallon be achieved by the early 1980's. Table 13 translates these overall improvements in efficiency into the various car sizes.

This improvement can be achieved by a combination of improved efficiency for every car size and a shift to smaller cars. If the 1974 sales mix remained constant, the efficiency improvements shown on Table 13 will produce only a 25 percent average reduction in gasoline consumption. This corresponds to a 33 percent increase in miles per gallon from 13.9 to 18.5. In this event, greater improvements would be required within each car size category to fulfill the Administration's goal.

Reductions in Engine Power Requirements

- *Weight:* A reduction in engine power requirements without affecting passenger carrying capacity or overall utility can be accomplished by a reduction in car weight. For example, a 400-pound weight reduction in a 4,000 pound car will provide about an 8 percent fuel economy improvement in city-suburban type driving. Even larger reductions are possible in heavier cars. Weight reductions are already being implemented by the auto industry as new models are introduced into the marketplace. The rapidity with which this effect can be fully realized must await appropriate capital availability, as significant weight reductions can only be accomplished by capital intensive changes in model configurations.

- *Transmissions and Axles:* Changes in transmissions and axles can also improve fuel economy with about a 6 percent improvement in city-suburban type driving and 20 percent in freeway type driving. The potential from these options is an overall improvement of 10 percent in fuel economy. The transmissions in use today will significantly affect the size of this potential gain. At the moment, it appears that a 4-speed automatic transmission with direct drive (except for low gear) would be the most efficient from a

TABLE 13

ESTIMATED PRACTICAL EFFICIENCY IMPROVEMENTS FOR VARIOUS CAR SIZES

	Miles per Gallon			Gallons per Mile (Index: 1974 Model Year = 100)		
	1974 Models	Early 1980's Models	Percent Improvement	1974 Models	Early 1980's Models*	Percent Improvement
Standard	10.7	15.5	45	129	90	31
Intermediate	12.1	16.7	39	114	84	28
Compact	13.8	18.4	33	101	75	25
Subcompact	22.3	25.6	15	62	54	13
	13.9	20	43	100	70	30

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* Assumes 1975 emission standards and no weight increase due to safety standards.

fuel consumption and performance standpoint. The torque converter lock-up feature accounts for most of the fuel economy gain when used in conjunction with low axle ratios. The addition of a fourth gear is not cost beneficial, because first cost exceeds life-time fuel cost savings. The fourth gear, however, does restore acceleration performance without penalizing fuel economy.

It is important to realize that while these changes in transmission characteristics can increase fuel economy, they also will increase emissions significantly. Changes will be required in engine calibrations to make compensatory reductions in emissions by the engine modification route. Progress in utilizing this option, therefore, may be slow because of the emission control complication.

- *Tires:* The use of radial ply tires can provide an estimated improvement in fuel economy of 2.5 to 5 percent. Many manufacturers have already taken advantage of this option and many 1975 cars are supplied with radial tires.
- *Wind Resistance:* Present vehicle drag coefficients indicate that improvement in vehicle wind resistance can be accomplished. Depending on current configurations the amount of potential improvement varies widely. However, by reducing the aerodynamic drag coefficient by 10 percent and the frontal area by 5 percent, 70 MPH fuel economy will increase by approximately 6 percent while the 55 MPH fuel economy will improve by about 3 percent. At speeds below 35 MPH the aerodynamic drag effect is minimal.
- *Accessories:* Accessory efficiencies can also affect total vehicle fuel economy. A 10 percent improvement in accessory efficiencies would improve overall fuel economy by almost 2 percent; based on an estimate that 20 percent of total vehicle fuel consumption is consumed by accessories. It is estimated that the total potential savings in power requirements for engine-driven accessories (i.e., air conditioning, engine fan, water pump, and alternator), could give an estimated 4 percent in fuel economy. Air conditioners and engine fans offer the largest potential. These improvements are being instituted by the vehicle manufacturers as rapidly as possible, but their overall adoption will take several years.

Improved Engine Design

There is always the potential for improvement in fuel economy through engine design modifications such as improved combustion chamber design. Table 12 indicated that a 5 percent increase in efficiency of conventional piston engines is probably the maximum available. The extent to which such an improvement will be available will vary widely depending upon the particular engine.

"Economy" Cars

- *Smaller Size:* Vehicle size can also have a major effect on gasoline demand. Table 14 shows the approximate relative gasoline consumption per mile in relation to vehicle size. Personal choice of car size reflects the driver's feelings regarding safety, comfort, and styling, and the economics of operating costs as well as first cost. Due to the present economic situation, it is difficult to project future customer demand. Table 15 presents several possible sales shifts which could reduce gasoline consumption of given model year cars by 5 to 15 percent if sales mix change alone were the only factor considered in improving fuel economy.

TABLE 14

EFFECT OF VEHICLE SIZE ON GASOLINE CONSUMPTION
(Index: Standard Size Vehicle = 100)

	Approximate Relative Gasoline Consumption per Mile
Standard Size	100
Intermediate	90
Compact	80
Subcompact	50

TABLE 15

ALTERNATE SALES MIXES FOR REDUCED GASOLINE CONSUMPTION
(Percent)

		Reduction in Gasoline Consumption				
	1974 Sales Mix	5 Percent		10 Percent		15 Percent
		Alternate Sales Mixes to Achieve Reductions				
Standard Size	27	12	17	11	7	5
Intermediate	20	25	15	20	10	10
Compact	25	30	35	25	45	35
Subcompact	28	33	33	44	38	50
	100	100	100	100	100	100

The achievement of 10 percent gasoline savings would entail substantial decreases in sales of standard and intermediate size cars which appears to be an extreme assumption. The sales mix change required for a 15 percent savings is unrealistic, since improvements in conventional size cars, as discussed in previous sections, are a more feasible source of gasoline savings. However, differences in relative prices of the cars, the cost of fuels, and the state of the economy may interplay and dictate otherwise.

- *Power-to-Weight Ratio:* In many cases a reduction of engine size can improve fuel economy. By increasing the 0-60 MPH acceleration time of a 3,800 pound car from 13 to 17 seconds, fuel economy can improve by 5 percent. Reduced acceleration performance of large and mid-size cars to that of small cars can increase miles per gallon efficiency by 15 and 10 percent, respectively. However, the public may be reluctant to buy significantly lower performing vehicles. A too low power-to-weight ratio increases emissions which results in less economical engine calibrations that are required to maintain emission levels.

  In many cases larger engines have been chosen for specific vehicle applications so that emission requirements can be met. For instance, the difference between federal and California emission standards for the 1975 model year has meant that many manufacturers do not market the lower power-to-weight ratio option for many vehicles in California because of the state's higher emission standards. Even though a lower power-to-weight ratio will improve fuel economy, emission requirements may preclude such advantage.

Effect of Emissions and Safety Standards on Passenger Car Fuel Economy

Both safety and emission control requirements have an adverse effect on fuel economy. Most safety requirements add weight to a vehicle. As previously pointed out, weight reduction is a significant option for improving fuel economy. The effect of emission requirements on fuel economy is more subtle. Engine adjustments (such as spark timing, fuel-air mixture, etc.) must be made to provide minimum emissions as opposed to maximum fuel economy. The engine settings for minimum emissions and those for maximum fuel economy are not the same and result in reduced fuel economy when set for minimum emissions. The effects of safety and emission requirements are discussed in more detail in the subsequent portions of this section.

Safety Effect

Present safety standards (issued and proposed for future years) will have a major influence on determining total vehicle weight which in turn, affects fuel consumption. The relationship between increased weight and fuel consumption for a city-suburban driving schedule is almost linear. Seven to 8 more gallons of fuel are required for each additional 100 pounds of weight per 10,000 miles of driving. However, these increases do not take into consideration the fact that as vehicle weight increases, performance is reduced. Therefore, valid comparisons of fuel economy potential can only be made between cars with equal performance. To compensate for the performance effect, a factor of 11 to 15 gallons per 100 pounds per 10,000 miles is frequently applied depending on car size. An additional problem arises because heavier suspension components are required for increases in body or engine weight.

Among the requirements considered by the Federal Government for the time period of this report is one that calls for an increase in the speed of the occupant protection standard barrier crash test from the present 30 MPH level to 45 or 50 MPH for the 1981 model year. Experience with experimental safety vehicles indicates this could add 375 to 1,000 pounds to vehicle weight. Adding this weight to the weight penalty associated with current safety standards would result in about a 25 percent increase above unregulated vehicle weight for safety regulations. This 25 percent increase in car weight would negate about two-thirds of the overall 30 percent reduction in gasoline consumption which could be achieved by employing all the factors discussed in the previous section.

Emission Effect

Table 16 illustrates the range of effects various emission requirements could have on fuel economy. The figures are based on the 1973/1974 emission requirements and the EPA urban/highway fuel economy schedules weighted on a ratio of 55/45. In the 1975/1976 model year, the catalytic converter is being employed to provide the final hydrocarbon-carbon monoxide (HC-CO) cleanup in the exhaust system which permits basic engine adjustments for increased fuel economy rather than minimum emissions. The fuel improvement from 1973/1974 to 1975/1976 varies from at least 20 percent in some models to a slight loss in others. EPA reports an average 13 percent improvement for 1975 models *versus* 1974 models. Part of the gain is due to a shift in the fuel economy control approach from basic engine modification hardware to the use of catalytic converters and part to factors not related to emission controls. At present, the continued use of catalytic converters is in question and thus, the gains in fuel economy associated with this approach may be lost.

If the more stringent 1977 or 1978 statutory standards are required, fuel economies will decrease as engine adjustments are made for minimum emissions. It is estimated that 1977 standards will result in reduced average miles per gallon of 1977 models over 10 percent below 1975/1976 models. It is estimated that 1978 standards which can only be modified by legislation will reduce average miles per gallon of 1978 models by an additional 15 percent to a miles per gallon index of 75 to 95 *versus* 100 for 1973/1974 models. It may be possible to regain some of this fuel economy loss by the application of other sophisticated emission control hardware in future years. Whether or not this will ultimately occur in a product which consumers are willing to purchase is not known.

TABLE 16

EFFECT OF EMISSIONS CONTROLS ON PASSENGER CAR FUEL ECONOMY

U.S. Emissions Standards*	Regulated Emissions (Grams per Mile) HC	CO	NO_x	Relative Average Fuel Economy (Index: 1973/1974=100)
Uncontrolled (pre-1970)	15.0	90.0	6.2	115
1973/1974	3.0	28.0	3.1	100
1975-1976 (Interim)	1.5	15.0	3.1	95-120
1977 (Original)	0.41	3.4	2.0	85-95
1977 (Interim)	1.5	15.0	2.0	90-115
1978 (Current Statutory)†	0.41	3.4	0.4	75-95

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* California limits not shown.

† Satisfactory hardware emissions performance and durability have not been demonstrated.

Even if more sophisticated hardware is developed to the point where it can be applied to the automobile to meet some of the more stringent 1977 or 1978 standards, it might be possible to have improved fuel economy with the same sophisticated hardware if less stringent emission requirements were permissible. Evidence indicates that there will likely be some trade-off between maximum fuel economy and minimum emissions. Government policy makers must provide guidelines for national priorities in this area.

Currently, Congress is considering various proposed revisions to the present statutory emission standards. The HC, CO and NO_x levels vary widely among the proposals but are within the ranges presented on Table 16. These plans also differ as to time schedule for implementation. Due to the diversity of the proposals, it is difficult to analyze their relative impacts on fuel economy. However, most of the plans would result in future cars with lower efficiencies than 1975/1976 models.

Any change in statutory standards beyond 1977 requires Congressional approval. Actions to freeze standards at current 1975/1976 levels should be considered for the following reasons:

- The need to balance air quality with energy conservation was not considered in the 1970 Clean Air Act.
- Scientific information relating automobile emissions and air quality developed in the past four years suggests that

the present NO_x and other standards may be overly restrictive.

- The number of cars on the road in 1985 is expected to be much lower than was envisioned at the time the 1970 Clean Air Act was written. This in itself will improve air quality.
- Present standards will continue to improve air quality for the next 10 years as older cars are replaced by newer ones. Freezing standards at 1975/1976 levels will continue to effect substantial reductions in pollutants. Additional reductions that could be expected from statutory standards beyond 1977 would be small through the early 1980's.
- Freezing standards at 1975/1976 levels will facilitate development of new engines and control systems which, while potentially highly efficient, are incapable of meeting scheduled statutory standards. Examples of possible improvements are the stratified charge engine and the lean burn principle. Some versions of these innovations have been implemented while others are under development. All of these programs are inhibited by the existence of presently scheduled statutory standards because of their short compliance times.

Altered Travel Characteristics

There are three areas where changes in travel characteristics by 1985 provide potentials for fuel conservation that are significantly different than those developed in Phase I. These areas are carpools, 55 MPH speed limit, and improvements in traffic flow.

Carpools

The Phase I report gave 3.0 persons as the realistic average loading for standard passenger-car carpools. However during 1974, company sponsored van pool programs have shown that these 10 to 12 passenger vehicles can be a significant component of an organized carpool effort. By 1985, vans could provide for about 20 percent of work-trip carpooling. In addition, as a result of planned national programs to maximize automobile passenger loads, participation in commuting carpools should be at the practical maximum level; estimated to be 75 percent of all automobile work trips. With maximum carpooling, the average load of all carpools would be 4.0 persons per car. In the 1972 base case, private passenger vehicle work-trip travel used 20.2 percent of total transportation fuel. Using this base, the savings in transportation fuel as a result of increased carpooling would be 7.3 percent over the current level and 4.9 percent over estimated 1978 levels, if maximum carpooling were achieved. A detailed discussion of carpooling is included in Appendix G, Exhibit I.

55 MPH Speed Limit

Most of the highway travel at the 55 MPH speed limit will occur on the Main Rural Roads.* Relative fuel consumption at the normal 55 MPH speed distribution for Main Rural Road travel with 1973 as 100 would be 94 for 1974 and 90 for 1985.

In the 1972 base case, travel on Main Rural Roads used 19.3 percent of total transportation fuel. The reduced speeds at the present level of compliance and at the normal 55 MPH assumed for 1985 would result in percentage reductions in the base case for total transportation fuel of 1.2 percent in 1974 and 1.9 percent in 1985. A detailed discussion of the 55 MPH speed limit is included in Appendix G, Exhibit I.

Improvement in Traffic Flow

Traffic control measures such as curb parking prohibitions, one-way streets, and traffic-responsive signal controls can improve the flow of traffic on urban arterial streets. It is estimated that the use of these measures could eliminate between 0.5 and 2.5 unnecessary stops per vehicle mile of travel. By emphasizing programs of these types, it is estimated that traffic flow improvements for the next 10 years could result in the elimination of one unnecessary stop, and a 30-second wait per vehicle mile of travel on urban arterial streets during morning and evening peak traffic periods in 1985. Studies have shown that the average extra fuel use for each such stop-and-wait delay is 0.01 gallon. Travel on the urban arterials during the peak periods is 18 percent of total urban travel, and in the base year, 8.8 percent of total transportation fuel use. By 1985, the traffic flow improvements should result in a 9.9 percent reduction in peak period fuel consumption and a 0.88 percent reduction in total transportation fuel use.

Commercial Trucking

Historically, the Nation's commercial trucking industry has accounted for almost all local cargo transportation and about one-quarter of all inter-city freight ton miles. The continuation of the energy-saving strategies implemented during Phase I will result in additional fuel savings in the 1979-1985 time frame. However, a point of diminishing returns will ultimately be reached. For example, once a truck fleet has converted all of its trucks to radial tires, no further savings can be expected from this strategy.

One area where fuel savings can continue to increase is the ongoing effort toward improving load factors involving shipper coop-

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*Main Rural Roads: A Federal Highway Administration grouping of approximately 600,000 miles of rural highways is made up of the rural Interstate and Federal-Aid Primary System and other major rural roads. The Main Rural Roads carry at least 75 percent of all rural highway travel.

eration in such areas as: scheduling flexibility, increased size of individual shipments, and consolidation of shipments in both pickup and delivery and inter-city movements. To date, the results in these areas have been quite rewarding. With an increasing awareness on the part of carriers, shippers, and concerned government agencies as to the need for continued progress on fuel savings, more cooperation and constructive results can be expected in the future. In examining and evaluating possible measures for the conservation of truck fuels, one of the major problems encountered is the lack of a good method to measure fuel economy. This lack has been noted by the Department of Transportation (DOT) and the EPA.*

Technological improvements designed specifically with energy savings potential in mind will be incorporated into the vehicles utilized by commercial motor truck fleets. Fuel conservation strategies initiated by the motor carrier industry will also continue in the future. Regulations and laws often preclude the application of many fuel-saving opportunities; however, technologically based efficiency improvements may be available, and if utilized by 1985, may improve the fuel efficiency of commercial truck fleets. Areas of potential fuel conservation in the trucking industry are contained in the following discussion.

Government Policies and Regulations

Many departments and agencies have been established and numerous laws have been enacted by federal and state governments to provide for the orderly growth and the ensured availability of adequate commercial trucking services throughout the economy. Another purpose of these departments, agencies, and laws is to ensure health and safety protection for the Nation. Unfortunately, the conflicting goals of some policies and regulations promulgated by government result in penalties in terms of fuel efficiencies.

Vehicle design regulations promoting safety and environmental protection are recognized as being necessary. However, questions have been raised that current requirements may be overly stringent. It is suggested that in the area of new motor vehicle requirements more consideration should be given to cost-benefit studies and to a coordinated "systems approach" in regulation.

The diversity among the state laws governing the size, weight, and type of tractors and trailers operating within each jurisdiction promotes inefficiencies and reduces productivity. A standardization of state codes could result in increased productivity and thus fuel savings.

Consideration should be given to the possible fuel penalties that might result from the conflicting objectives of regulations emanating from various agencies. There should be a continuation of

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* U.S. Department of Transportation and the U.S. Environmental Protection Agency, *Potential for Motor Vehicle Fuel Economy Improvement--Report to the Congress*, Washington, D.C.: October 24, 1975.

constructive measures which have already been fostered by the Interstate Commerce Commission (ICC) and encouraged by FEA and DOT. Through closer cooperation towards constructive ends, it is foreseeable that significant strides toward substantial energy savings can be realized.

Improved Vehicle Design

The streamlining of truck bodies and improvements in transmissions and engines can yield fuel savings in the future.

- *Streamlining:* By streamlining both tractors and trailers, the amount of air resistance caused by a vehicle moving along a highway can be reduced. The National Science Foundation has funded aerodynamic research to develop devices which could result in fuel savings for the motor freight industry. A discussion of the advantages and disadvantages of these devices is given in Appendix G, Exhibit II.

- *Transmissions and Engines:* As a result of the national 55 MPH speed limit, many companies when placing orders for new tractors are specifying that the transmission be geared to give maximum efficiency of operation within that speed limit. Research is continuing to improve both the diesel and the turbine engine. The efficiency of both of these engines appears to be increasing at an equal pace. One problem affecting the general use of the turbine engine, at least in the near future, is the complex transmission required to reduce the 10,000 revolutions per minute (RPM) of the engine. Today, about 80 percent of local cartage trucks are powered by gasoline engines. If the efficiency of the diesel engine improves and pollution control devices increase the fuel consumption of gasoline-powered engines relative to that of diesel-powered engines, a major shift to diesel-powered trucks will occur. This shift has already begun in California. This shift is not a complete solution to the problem because diesel engines cost more, weigh more, and are noisier than a comparable gasoline engine.

When government regulation forces disproportionate attention to be given to one phase of design, others will generally suffer. An example of this is in gasoline vehicles where air pollution regulations have resulted in reduced amounts of certain compounds in the exhaust at the expense of increased fuel consumption, maintenance complexity, and increased operating costs. The present method of different governmental agencies regulating separate parts of the vehicle with little interagency coordination could be improved.

Trucking industry engineers have estimated that if all of the government regulations affecting vehicle performance as proposed in the late fall of 1974 are promulgated as written, the end result will mean an addition of 1,500 pounds to total vehicle weight. Since the maximum gross vehicle weight (weight of vehicle and cargo) is set by law, this could mean other things being equal, that the revenue producing freight carried by a tractor-trailer combination would have to be reduced by 1,500 pounds. This would result in a loss of revenue, a reduction in productivity, and an increase in the amount of fuel consumed relative to the amount of freight transported. Therefore, a "systems approach" in regulations could prove beneficial to vehicle design.

Improved Vehicle Usage

Since the Nation faces a continuing dependence on insecure imported supplies of petroleum and the prospect of steadily rising fuel costs, there is a pressing need for greater productivity in all business, industrial, and transportation users of petroleum. Looking at the Nation's future energy needs, each mode of transportation must devise methods for transporting a given unit of freight as efficiently as possible. This need for increased transportation productivity applies to all types of freight. If more units of a given type of freight can be moved per shipment, the cost per unit for transportation and the amount of fuel consumed per unit will decrease. Methods of improving vehicle usage are examined in the following discussion.

- *Radio Communications:* The use of radio communications as a tool for saving fuel and increasing productivity for the trucking industry will find its greatest application in local pick-up and delivery operations. It is estimated that in pick-up and delivery type operations, four trucks can do the work of five if radio controlled, allowing more freight to be handled per truck. If technology in this area continues to improve, utilization of radio communications on a nationwide basis can be an effective tool to improve truck efficiencies. The extent to which radio communications can assist in reducing the amount of fuel consumed by the trucking industry depends on the type of operations and the location of the motor carrier.

- *Twin-Trailers:* In highway freight transportation, one immediate method of increasing productivity and reducing the amount of fuel consumed in the eastern and southern regions of the United States lies in permitting the operation of twin trailer combinations. Twin-trailers--a combination consisting of a truck tractor drawing two short semi-trailers connected by a converter dolly--are now operating in more than half of the states. To provide low cost, efficient highway transportation to the Nation in the future, the trucking industry must be able to utilize its most efficient and productive units in all states. Action to permit the operation of twin-trailer combinations in the remaining 20 states which prohibit or restrict these units could provide a significant boost to transportation productivity, save fuel, and reduce noise pollution as well as truck traffic.

- *Rates and Packaging:* The publication of rate schedules with greater emphasis on freight density could result in fuel savings for the motor carrier industry. For example, freight density could be increased by shipping goods in a nonassembled state or prior to final packaging.

- *Gateway and Deviation Procedure:* In early 1974, the Interstate Commerce Commission (ICC) established proceedings to eliminate the so-called gateway point for irregular route carriers with the objective of conserving fuel. The gateway elimination ruling does not apply to general freight carriers who operate on fixed routes usually at regular intervals.

- *Pooling of Services:* The ICC is allowing more pooling of service among carriers. The opportunity to increase efficiency through pooling arises where numerous carriers have authority to serve a sparsely populated area and where traffic flow is insufficient to support regular daily operations by each carrier. A continuing overview has been provided to ensure that monopolies created by the pooling of services do not result in the raising of prices and/or limiting the quality of service.

- *The Motor-For-Motor Substitute Service:* An experiment approved by the ICC with current fuel conservation efforts in mind, has proven to be a successful means of saving fuel in selected inter-city operations by allowing carriers to limit the extent to which trucks are moved with less-than-full loads between points. The ICC has recently approved the tariff of the Middle Atlantic Conference Carriers, allowing them to utilize this service to all points and places served by them. The program cannot solve all traffic imbalance problems but it does hold the promise of constructive progress.

- *Improved Freight Handling:* The Equipment Interchange Association has been responsible for significant improvements in the free flow of goods among motor carriers. This is being accomplished by agreements among the participants to expedite the handling of inter-line freight where the destination of goods crosses operational boundaries. The program has resulted in more control and efficiency for inter-city drivers and also in conservation of fuel. This program also has the encouragement of the ICC.

AIRWAYS

The current consumption of aviation fuels represents about 11 percent of the total fuel used in the transportation sector. This consumption level resulted from the steady growth in air travel due to public demand for its convenience and speed. Air transportation accounts for 80 percent of the public carrier inter-city passenger miles in the United States and 93 percent for travel to cities outside the United States. Also, over 6 billion ton miles of cargo service is provided by airlines. Technological advances hold long-term promise for continued improvement in air transportation energy utilization.

Current Technology Not Yet Fully Implemented

Since the beginning of aviation there has been a steady stream of technological advances that has made this mode safer, more reliable, more comfortable, more convenient, and more energy efficient. Today, there exists advanced technology that has not yet become fully employed in the total U.S. airline fleet. This currently available advanced technology will provide all, or nearly all, of the improved energy utilization that can realistically be expected during the Phase II period.

An example of this kind of technology is the phasing out of pure turbojet-powered aircraft and replacing them with more efficient turbofan-powered aircraft, and even more efficient high by-pass ratio, turbofan-powered, wide-bodied aircraft. Also, so-called "stretched" aircraft with better seat-mile cost characteristics continue to be developed and to take their place in the airline fleet.

While it is impossible to accurately project the future impact of this current advanced technology, the following tabulation depicts the improvement in available ton miles (ATMS) of transportation per gallon of fuel consumed that has been achieved in recent years. The period covered includes the life span to date of the wide-bodied aircraft which numbered about 300 in the U.S. scheduled airline fleet at the end of 1974.

AVAILABLE TON MILES PER GALLON PER YEAR

1969	1970	1971	1972	1973	1974*
4.22	4.39	4.65	4.72	4.82	5.10

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* Preliminary (9 months)

Another promising aspect of technology that should support a change in the procedures for airspace use is improved aircraft altimetry systems. These improved systems are currently installed in most of the U.S. airline fleet. With a change in Federal Aviation Administration (FAA) rules concerning vertical spacing between usable high altitude flight cruising levels, more aircraft could cruise at the optimum efficient altitudes. Another example of existing technology currently being implemented is an air traffic control automation base which allows improved identification and routing of aircraft en route and in airport terminal phases of flight. Also, major efforts are under way to improve the efficiency of airports. Any resulting reduction in delays and circuitous routings provides better fuel utilization.

New Technology in Research Stage

Beyond the 1985 period, new advances in technology now being researched and stimulated by the changed fuel situation hold promise for further improvement in energy utilization when the next generation of aircraft and engines comes into airline service (perhaps beginning in the late 1980's). R&D for major improvements in aircraft energy efficiency is a top priority of the National Aeronautics and Space Administration (NASA). NASA's near-term technologies (those technologies NASA believes can be developed before the early 1980's) include: supercritical aerodynamics, composite materials, advanced propulsion, improved digital flight controls, and "active" controls. NASA claims these near-term technologies could allow fuel consumption to be reduced 35 percent below present day wide-bodied transport aircraft. As is the case with current advanced technologies, any new technologies will take years after initial introduction to become fully effective throughout the airline fleet.

Possible Technological Advances in the Distant Future

NASA's long-term technology which might cut fuel consumption another 20 percent from today's wide-bodied aircraft level includes: laminar flow control using boundary-layer techniques and a revolutionary concept of compliant skin aircraft. Other future possibilities include unconventional designs such as flying wings using the span-distribution load concept.

Use of liquid hydrogen as an alternative fuel is under study but would require totally new aircraft designs and hydrogen production and supply distribution systems which are nonexistent at this time. If the decision were made to use liquid hydrogen, the earliest date for inception is the 1990-2000 period.

RAILWAYS

The railway mode is recognized as one of the most efficient means for transporting goods. This mode utilizes only 3 percent of the total fuel consumed in the transportation sector and has low emission levels. Railroads account for nearly 39 percent of all inter-city freight ton miles. Though railways consume only a small percentage of the total fuel used, a potential exists for improved efficiency within this mode. The following is a description of the areas where, in light of on-going research, energy conservation and environmental protection could result by railroads.

- The present diesel-electric locomotive is a highly efficient energy conversion system. It achieves high efficiency levels in fuel utilization and, therefore, no potential exists for significant changes in fuel consumption.

- In view of the cost of fuel, much attention has been paid to operating practices which would optimize fuel utilization.

- The diesel engine is a relatively low source of pollutants. Utilizing present engineering design modifications, it is compatible with projected emission standards.

- In the area of environmental controls, only noise reduction technology presents a possible threat to the efficiency of the diesel locomotive.

- Gas turbines, direct coal-fired turbines, or other forms of basic energy conversion systems do not appear promising as a replacement for the diesel engine as a self-contained power plant on a locomotive.

- Technology for the adoption of the electric locomotive has been developed. Electric locomotives are being used in a few selected sites in the United States. The electric locomotive is advantageous because a variety of fossil and nuclear fuels can be used to generate electricity which in turn, provides power for the locomotive. However, the high capital cost of electric systems and the necessity for insuring continuity of power at a time when utilities are being pressed to supply present electric power demands, tend to stand in the way of an early and more general utilization of this advancement.

Train Performance Calculators

A number of new analytical tools are becoming available to the railroad industry. These permit careful calculations regarding the forces in trains and the energy involved in moving trains with various loads at various speeds. Earlier versions of train performance calculators have been extensively applied in more efficient design of traffic patterns and the determination of optimum operating conditions. Both lead to minimizing fuel consumption. While these tools can also be used to minimize forces in trains, thereby increasing equipment life and reducing potential for derailment; it is expected that their application will also increase fuel optimization.

Emission Controls

New techniques to measure visible emissions have been developed. These techniques are expected to be applied extensively in locomotive repair shops and will assure that repairs to locomotives are consistent with environmental controls, and that the lower invisible emission levels from current new locomotives are maintained. The technique applied to assure compliance with environmental controls on visible emissions will also contribute to maintenance performance which ensures optimum fuel consumption.

One negative factor influencing fuel consumption and engine efficiency is emerging in the EPA concern over noise emissions from locomotives. If a requirement were introduced for mufflers, some deterioration in the effective life of a locomotive and in probable fuel consumption may result. The back-pressure increase that may result from a muffler obstruction in the flow of exhaust gases could reduce the efficiency of combustion in the diesel locomotive. However, evidence is emerging which indicates that some mufflers may be less restrictive than the spark arrestors they are intended to replace.

Alternate Power Sources for Locomotives

Gas turbine locomotives have been constructed but have not been found effective in providing the large, variable amounts of energy that must be generated. Accordingly, other internal and external combustion engines have been examined; but none, with the possible exception of the electric locomotive, has been found to be as attractive as the diesel-electric locomotive which is now in service.

Diesel Engines

Some progress has been made by changing the design details for locomotive diesel engines to reduce oxides of nitrogen without changing or increasing the carbon monoxide emissions. The present diesel locomotive as modified, appears to be compatible with long-term emission standards.

WATERWAYS

Marine transportation energy productivity (the ton miles of cargo delivered per unit of energy consumed) is principally a function of the following factors:

- Vessel speed
- Payload per voyage
- Distance between ports
- Fuel consumption en route
- Load/unload rate
- Fuel consumption at port.

In order to raise both vessel productivity (revenue tons hauled per year) and energy productivity, it is more economical and more energy efficient to increase payload per voyage rather than increase vessel speed. This is due to vessel construction, operating costs, and fuel consumption which are directly related to power requirements. For this reason, technological improvements in high-volume bulk cargo, marine transportation are more economical when directed to increased vessel or barge-tow displacement combined with quicker cargo loading and discharge systems. Nevertheless, quick-delivery capability is an important requirement in containerized and other nonbulk cargo and passenger marine transportation. Here, as well as within the overall vessel design parameters of bulk cargo service, improvements in vessel speed, and fuel consumption rates at varying speeds offer significant opportunities for increased vessel productivity and fuel consumption efficiency.

Available Technology

Vessel Displacement

Oil tankers having a displacement of 500,000 deadweight tons (DWT); ore-bulk-oil combination vessels of 250,000 DWT; dry cargo barge-on-ship or container vessels of 250,000 DWT; integrated tug-barge vessels of 100,000 DWT; and inland waterway tows of 50,000 DWT are currently in use or under design. One example of potential energy savings follows. On a round-trip voyage from the Persian Gulf via the Cape of Good Hope to the U.S. Gulf Coast and back, it is estimated that a 120,000 DWT tanker consumes about 60 percent as much fuel per ton of cargo transported as a 58,000 DWT tanker; whereas a 265,000 DWT vessel consumes only about 45 percent of the fuel required per ton of cargo as the 58,000 DWT tanker. Yet, due to the 25 year life of many vessels; port draft and handling size limitations; bottlenecks in inland waterway channel depths and lock throughput capabilities; and limited requirements for certain routes; the average size vessel or barge-tow currently in use is but a fraction of the current technological optimum.

Propulsion Efficiency

Present steam-turbine and diesel-engine drive power plants have thermal efficiencies of about 25 and 35 percent, respectively, while the present marine gas turbine has a thermal efficiency of about 23 percent. Although this puts the present gas turbine engine at a fuel efficiency disadvantage for most bulk cargo marine services, its lower weight to power ratio of 1 to 2 pounds per horsepower compared to specific weights of 15 to 35 pounds per horsepower for steam-turbines and diesel engines makes marine gas turbines the most feasible power source for high-speed, small-displacement hydrofoil and surface-effect ships. Numerous small improvements in the fuel efficiency performance of each propulsion system including not only power plants but also drive trains and propellers, can be incorporated into the construction of updated versions. Examples of such improvements are: computerized fuel and air-intake monitoring and vessel-operating control systems; advanced reheat steam propulsion; modern marine radiant boilers; improved medium-and slow-speed diesel engines; and controllable pitch propellers.

Hydrodynamic Efficiency

Among the principal areas of improved hydrodynamic efficiency is the reoptimization of ship, barge, and tug hull design to reduce drag and improve wave-making resistance, stability, cargo storage space, and seaworthiness. Other present technology includes the use of various hull coatings and films to reduce fluid friction; optimized barnacle removal and hull cleaning schedules; and increased use of integrated tug barge systems. Integrated tug barge systems employing a unified-hull configuration of pusher-type tug locked to the notched stern of the barge combine the improved hydrodynamics, speed, and maneuverability of a ship-type integrated-hull design. Such a configuration results in no relative movement between barge and tug as compared to a towed ocean barge with the flexibility of operating the tug independently of the barge.

Waterway System Capacity

Capacity restraints potentially limiting fuel efficiency improvements through use of larger displacement vessels exist with respect to deepwater ports accommodating very-large and ultra-large size cargo carriers (VLCC's and ULCC's); draft, length, and width restrictions on major inland rivers; barge and vessel lock handling limitations; and bridge obstructions such as narrow spans between piers and limited vertical clearances. The Deepwater Ports Act of 1974 enabled proposed construction of deepwater ports on the Atlantic, Gulf, and Pacific Coasts. Plans are also moving ahead for relief of some of the bottlenecks on the Mississippi, Ohio, and Illinois Rivers. However, anticipated future traffic growth requires additional capacity expansion by improving locks, removing obstructions, and dredging 12 foot channels in key segments of the inland waterway system. Provisions for 12 foot channels are calculated to boost capacity by about 40 to 50 percent. In addition, improved navigational and communication aids, weather advice, and icebreaking techniques are able to contribute to vessel fuel consumption efficiency.

Terminal and Cargo Handling Capability

Increased terminal and cargo handling capabilities can effect fuel savings by reducing vessel fuel consumption during the loading and unloading phases. These phases often represent a significant share of total round-trip voyage time. Shipboard and terminal cargo handling and placement, and data recording automation systems can effect significant savings. Ultimately these could be extended technologically to include completely automated, unstaffed loading and unloading systems. Container-ships, roll-on/roll-off vessels, and rail car ferries provide significant improvements in cargo handling efficiency. New and higher cargo capacity channels dredged in rivers, inland lakes, canals, and harbors as well as construction of high volume, highly automated intermodal transportation systems hold potentials for substantial unit fuel savings. New and larger capacity marine terminal berths, storage areas, computers, and overhead cranes required to achieve such increased automated cargo handling should provide economic benefits as well as overall marine fuel economies.

New Technology in Developmental Stage

Improved Gas-Turbine Power Plants

Improved gas-turbine engines which employ a supercharged heavy duty gas turbine and steam cycle as a propulsion plant have been proposed for high-speed U.S. Navy vessel applications. The combined-cycle system raises calculated all-purpose thermal efficiency to the 31-32 percent range. This exceeds that of conventional steam-turbine power plants and approaches that of diesel-engine units.

Improved Nuclear Power Plants

Until recently, nuclear power plants for marine applications have not been competitive with conventional plants except possibly for submarine cargo transports under thick ice fields and other very high horsepower applications. The special shielding and containment equipment, elaborate safety and control devices, and highly skilled personnel required all contributed to the past noncompetitiveness of nuclear plants. However, the recent tripling or quadrupling of fuel prices for conventional plants has tended to erode their competitive advantage over nuclear power plants. Further improvement of the design to include lower cost, lighter weight nuclear power plants combined with future improvements in commercial familiarity with and expertise in operating nuclear facilities, are expected to make nuclear power plants economically competitive with conventional power plants in addition to marine applications in the future.

Improved Hydrofoils and Hovercraft

Hydrofoils and hovercraft are presently competitive only in selected high-speed military, coast guard, commuter and difficult terrain freight service such as traversing rivers, swamps, and ice fields. However, recent engineering and feasibility studies indicate that further improvement in low weight-to-horsepower plants, conceivably the combined-cycle gas turbine or lightweight nuclear plants previously discussed, could make high speed vessels such as hydrofoils and surface-effect ships cost competitive in marine passenger and freight applications for craft having speeds of 40 knots and displacements of 1,500 and 3,500 tons. While such applications would probably be more energy intensive than larger sized conventionally powered vessels, nevertheless, they might represent improved fuel efficiency through intermodal shifts from higher fuel consumption highway or air carrier transportation.

New Waterway Routes

New waterway routes, extended intercoastal waterways or deeper, higher cargo capacity channels dredged in inland rivers, lakes, canals, and harbors will improve fuel conservation by permitting greater use of larger displacement barges and vessels. However, evaluations should be made of trade-offs between environmental considerations, net energy savings, and costs associated with the foregoing projects.

New Longer Range Technology

Closed-Cycle Brayton or Stirling Engines

Primarily closed-cycle Brayton or Stirling engines incorporating multi-fuel capability and high efficiency are now in the R&D stage. Such closed systems are believed to have the technological capability to achieve 30 to 35 percent system thermal efficiency at design rate power loads with very good efficiency at partial power loads.

Concepts for Future Power Plants

Naval architects are conducting research on improved aerodynamic sail structure vessels, such as the "Dyna-Ship" concept. This concept is designed to employ windpower, approximately 72 percent of the time in North Atlantic service, to propel a 17,000 ton vessel at speeds up to 20 knots; while using auxiliary conventional engines the remaining 28 percent of the time, at overall conventional fuel consumption rates of only 5 percent of that used by conventional cargo vessels.

Another new mechanical power transmission concept under R&D for both terrain and marine environments is the segmented magnet homopolar torque converter. This device is designed to convert unidirectional torque of constant speed, such as that provided by a steam-turbine prime mover into variable speed output torque in either forward or reverse directions. Advantages afforded by such a concept are an efficient, lightweight, low volume design with potential application over a wide range of speeds and horsepower ratings varying from hundreds to tens of thousands of horsepower.

URBAN PUBLIC TRANSIT

The Phase I report concluded that between 1974 and 1978, moderate net motor fuel savings could be achieved through more intensive utilization of existing and potential expansion possibilities of public transport systems. Additional energy savings of similar magnitude are anticipated in the 1979-1985 period. A major factor affecting mass transportation in the United States is its suitability to suburban living patterns. Evolution of urban public transit in the United States has particular relevance to contemporary urban travel.

In 1970, 784 million urban passenger miles were travelled in the United States, of which 7 percent were by various modes of urban public transit. Since World War II there has been a decline in the use of public transportation with the exception of taxicabs. During this period patronage reached its highest level at 23 billion rides per year. By 1972, public transit utilization was 6.6 billion rides. The greatest decline in public transportation rides took place outside the commuting to and from work areas which has resulted in greater crowding during peak load hours and under utilization during off-peak hours. This decline is attributable to dispersal of population outside of urban areas which has resulted in suburban living typified by low housing and population densities. Suburban living has fostered travel with a large number of origins and destinations more conducive to the private automobile than conventional public transportation.

Urban public transport systems consist of two principal modes--rail or other fixed guideway systems and those utilizing public roads. Motivation to increase utilization of public transportation will differ between urban areas. Expansion of fixed guideway systems will be limited. Costs for such systems are very high, presently averaging about $40 million a mile. These systems are generally limited to areas with high population density cores and to corridors with sufficient ridership potential. At present, 9 of the 25 largest urban areas in the United States have fixed rail systems in place or under construction (see Appendix G, Exhibit III, Table 30).

Increased Ridership

Expansion and modernization of existing rail facilities would be a potential incentive to increased ridership. Where fixed rail transit systems do not exist at present, consideration should be given to alternate modes which would utilize existing public roads. In many instances, public transport could be expanded most expeditiously by increasing the number of buses. Such expansion would depend on public acceptance and maintenance of load factors on an expanded bus system.

Public Acceptance

Public acceptance is of major import in increasing bus ridership. The dramatic decline in ridership on the Nation's bus, subway, and commuter rail lines over the past 20 years is principally attributable to the private automobile. With the dispersal of residences, shopping centers, job locations, schools, etc., feasible alternatives to private autos have become more difficult to implement. Even where public transport is an alternative, the private auto is preferred by the public because of service characteristics including: speed, comfort, privacy, and complete independence from any schedule. Stimulating a shift to public transit would require service characteristics approaching the private automobile, including more extensive coverage, shorter door-to-door travel times, more frequent service, increased comfort, etc. These are difficult goals for any public transit system to attain and their realization would be difficult to achieve.

Some steps could be taken to increase the attractiveness of urban public transport to potential patrons. First, travel time could be reduced by utilizing bus-only-lanes, priority access of buses to highways and tunnels, and bus-activated traffic signals. These would allow buses to increase their speed in urban streets. Second, more emphasis could be placed on systems that are fully or potentially demand-responsive. Currently, there are many on-going or planned experiments with Dial-A-Bus concepts. For example, one system's primary mission is to serve travelers between suburban residences and a commuter rail station. During off-peak periods, the system serves the needs for local travel among diverse origins and destinations. Although more work is required for computerizing the vehicle locating and routing functions, this type of service is beyond the pilot program stage. The average load factor may be lower than that currently achieved by scheduled buses since people will use this system like a taxi service, particularly during the off-peak periods. If so, operating costs could be very high and net energy savings insignificant.

The appeal of urban public transport can be increased through the cooperation between suburban communities and central cities in building efficient area-wide public transportation systems in which the various modes are planned and integrated carefully to provide the varied transportation services required by all potential users.

Maintaining Load Factors

The second element of major import in determining the extent to which the bus fleet can be expanded is the level of average load factor. This factor determines the potential net energy savings resulting from switching people from cars to public transport and also influences the operating cost per passenger carried. Increases in urban public transit trips will be largely for commuting to and from work.

Currently, over 80 percent of all work trips are made by car. These trips account for about 35 percent of total car miles driven. Public transit should be able to increase its role in this area. However, it must be recognized that public transit is most suitable to bring people into central districts. Places of work are spread over large geographic areas even in the main population centers. In the 10 largest population centers (New York, Los Angeles, Chicago, Philadelphia, Detroit, San Francisco, Washington, D.C., Boston, Pittsburgh, and St. Louis) about 47 percent of the employees live and work in the suburbs; only 17 percent live in suburbs and work in the city; 29 percent both live and work in central cities; and the remaining 7 percent live in the city but work in the suburbs. Increasing the number of urban buses could eventually result in lower average load factors and higher operating costs.

It is difficult to assess the potential savings in motor fuels resulting from expansion of urban public transport. Whatever the achievable savings, they will probably be small in absolute terms and relative to the total fuel consumed by the U.S. transportation sector. For example, if 100,000 urban buses were added to the present fleet of 50,000, net motor fuel savings from switching commuters from cars to buses would only be 79 thousand barrels a day (see Appendix G, Exhibit III). This is less than 2 percent of the gasoline currently consumed by the Nation's passenger cars. Such an increase in the urban bus fleet would require a considerable expansion in facilities for the assembly of buses, and the manufacture of components such as engines, axles, etc.

PIPELINES

Pipeline systems offer the potential of providing extremely energy efficient transportation for a limited number of materials. At present, most pipeline systems are employed in the movement of crude petroleum and petroleum products, and natural gas. Most likely, this situation will remain basically the same during the 1979-1985 period; however, a possible increase in the use of pipeline systems for transporting some solids, most notable coal, via slurry techniques could occur. Potential energy savings from pipelines are considered in the following dicussion.

Current Technology

- *Pipe Size:* The high level of energy efficiency that is available through the use of pipelines can be attained by maintaining a relatively high ratio of pipe diameter to material flow rate. This is typically the case in new pipeline systems. However, as the demand on a given pipeline system increases, throughput is raised by the addition of horsepower to the existing line, thereby reducing the energy efficiency of the system. As a result of this process, it is estimated that the average energy efficiency (800 BTU's per ton mile) of all U.S. pipeline systems is not particularly high.

  The above points out the key to energy conservation in the pipeline mode--the use of larger pipe sizes in the construction of new systems, and earlier "looping" (the addition of parallel pipe to an existing line) of in-place systems as flow rates are increased. The opportunity for energy conservation through the use of large pipe sizes will be limited in the post-1978 period. Future reductions in the growth rate of U.S. energy demand will diminish the need for expanded pipeline capacity unless additional usages are developed.

- *Exchanges:* The present crude oil and petroleum product transportation system is owned and operated by the private sector with each individual enterprise handling its own transportation requirement. Consequently, some amount of crude oil and product is transported in opposite directions by two or more individuals. There is a great deal of exchange activity wherein crude oil or product at one location is exchanged for crude oil or product at another location. However, a significant amount of cross traffic still exists. Much of this cross traffic is conducted through the pipeline system.

The elimination of some amount of pipeline transport through the use of exchanges, therefore, is an obvious energy saving device. However, implementation of the technique beyond its current level is not considered practical because more problems would be created than solved. The problems would arise from the necessity of creating some sort of central, intercompany, planning authority to determine the optimum transportation patterns. Such a system would, in the course of saving a small amount of energy, partially substitute a planned economic environment for a market economic environment. This, in turn, would serve to reduce the operating efficiency of the affected industry far more than the resultant energy saving would warrant.

- *Slurry Pipelines:* As identified in the Phase I study, coal slurry pipelines are being considered as an alternate to railroads or other modes for transporting coal from western fields to various load centers. (See Appendix H, Exhibit VI for a detailed discussion of slurry pipelines).

  As concluded in the Phase I study, the determination of whether or not to utilize slurry pipelines will likely be made on the basis of factors other than energy efficiency.

New Technology in Development Stage

- *Friction Reducing Polymers:* Injection of polymers into crude oil streams can substantially reduce friction within the pipeline. This results in a decrease in power requirements at a constant rate of flow or an increase in flow rate at a constant level of power input.

- *Liquid Pocket Reduction:* Liquids tend to accumulate in low places in gas gathering lines that are located in hilly terrain. Studies are under way to determine if "pigging" (cleaning of a pipeline by forcing a solid plug through the line) or some other means can be employed to reduce the pressure losses caused by this phenomenon.

- *Internal Pipeline Coating:* Coating pipelines on the interior has the dual effect of reducing corrosion and friction, the latter reduces the energy consumption of the system. Currently, gas lines are coated while liquid lines are not. The coating is normally applied prior to the installation of a new line, but "in place" coating of existing pipelines is in the developmental stage. The "in place" coating procedure would extend the length of pipeline available for applying internal coatings.

These three techniques are thought to offer very limited potential for energy conservation. Improvements in pump, compressor, or driver efficiencies would have much larger energy saving potential but do not appear to be in the offing.

Chapter Four

ELECTRIC UTILITY

Energy conservation potential in the electric utility sector in the Phase II, 1979-1985 period has been appraised emphasizing technological and operational changes which could exist on a commercial scale by the mid- or late 1980's. Additionally, attention is given to longer-range concepts which might contribute to efficiency improvement later in this century or early in the next. Also considered is the possible extent of fuel substitution during the next 10 years which could achieve reductions in electric utility use of oil and gas.

No attempt is made to estimate energy savings achievable through a coordinated plan of development of new technology and customer conservation efforts. Specific examples of possible savings are cited when such examples illustrate the relative potential represented by a given innovation or technical advance. The many technological changes discussed in this report should be viewed as possibilities and not as certainties. Only detailed economic evaluations can reveal which technological advances are commercially viable and the rate at which they can be introduced.

ELECTRICITY PRODUCTION EFFICIENCY

Generation Technology and Concepts Pertinent to the 1980's

Conventional Steam Cycle

The national average annual efficiency for fossil units is about 32.7 percent. This is actually below the high of 32.8 percent achieved in 1968. The Federal Power Commission (FPC) attributes this decline to a decrease in the quality of coal burned and to an increase in the use of residual oil to meet sulfur oxide emission regulations. These factors offset the effects of the improved efficiency of about 38 percent of new generating units installed as well as the retirement of older units operating at about 20 to 25 percent efficiency.

Light-water reactor nuclear units currently operate at about 30-31 percent thermal efficiency on an annual basis. Thermal efficiency for these plants is extremely important, despite the relatively low cost of fuel. When capability penalities are imposed on nuclear units in the form of fixed licensable thermal power ratings below design outputs, efficiency is reduced. Continued application of the proven steam-reheat cycle together with projected advances in steam inlet pressure will increase the efficiency level of these units to about 36 percent, corresponding to a 34-35 percent average annual efficiency. Since these units are planned primarily for base load operations, the actual operating annual efficiency level of the Nation's installed capacity of nuclear plants will approach that of the total installed fossil plants despite the difference between the efficiencies of the best units of each type.

Technology exists today to extend steam-cycle efficiencies to the 42 percent level. However, practical operating considerations and environmental limitations may impede the realization of this potential. Best plant thermal efficiencies are not expected to surpass 40 percent for either fossil or nuclear fueled plants.

Combined Cycle--Steam Turbine/Combustion Turbine

The national average annual thermal performance is expected to remain at about 33 percent for both fossil and nuclear units. Little difference in the efficiencies of these two types will be realized on an average annual basis because of the projected differences in loading practices. Of all types of thermal power generation, the combined-cycle power plant has the greatest potential for improved efficiency in the 1979-1985 period. A combined-cycle plant produces electrical power from a combination of combustion and steam turbines, with the steam generated by the heat of the combustion turbine exhaust. Thus, additional electrical power is produced without an increase in total fuel consumption over that required for the combustion turbines.

New conventional steam plants have a thermal efficiency of about 38 percent, compared to about 39 percent efficiency for current combined cycles, which should increase to about 42 percent by 1977. Improved combined-cycle efficiency can be realized by increasing combustion turbine inlet temperature. Currently, turbines operate at about 2,000°F. The combustion turbine industry has been increasing turbine inlet temperatures at a rate of 60-65°F per year. By 1985, it is expected the industry will achieve inlet temperatures of 2,700°F through material improvements and advanced cooling techniques. The resultant efficiency would be over 50 percent.

The combined-cycle plant can also use alternate fuels, such as synthetic oil or gas based on coal, oil from shale, and high-sulfur residual oil. These fuels may not be in as great a demand in other energy using sectors. The electric utilities can shift to alternate fuels efficiently, at the same time meeting expected environmental regulations, through technology now being developed. Two significant alternate fuel processes being developed for electric utility use are coal liquefaction and low-BTU coal gasification. Liquefied coal and synthetic fuel from oil shale can be used directly in the combined-cycle plant without downgrading plant efficiency. In addition, these fuels can be stored in tanks for use as required to meet the daily load cycle, or they can be shipped by pipeline, rail or barge to distant power plants. Advanced low-BTU coal gasification R&D programs in conjunction with combined-cycle power plants should be in operation by the end of this decade with commercial implementation in the late 1980's. These integrated plants should achieve thermal efficiencies of 40 percent as compared to 36 percent for an equivalent steam plant with stack gas clean-up.

Combined Cycle--Steam Turbine/Magnetohydrodynamic (MHD)

The MHD conversion process can be described as a generator which simultaneously operates as both a thermal expansion engine and an electric generator. Successful development of MHD generation could produce major energy conservation benefits by raising the efficiency of large central-station generating facilities. MHD generators, like other heat engines, are subject to economies of scale, and its inherently high temperature makes MHD an ideal topping cycle for present day steam electric technology. Overall plant efficiencies of 60 percent or better are predicted. More importantly, MHD can utilize native coal, oil refining residuals, chars, and other "dirty" fuels which would be difficult to use effectively in a more conventional manner. For a more detailed discussion of the MHD system see Appendix H, Exhibit I.

High Temperature Gas-Cooled Reactor (HTGR)/Closed-Cycle Gas Turbine System

While most gas-cooled reactors have been developed for use with steam-turbine power conversion systems, the potential benefits of a closed-cycle gas turbine driven by the reactor coolant gas have been recognized for some time. The Gas Turbine HTGR power plant is a combination of the Helium-Cooled HTGR and a closed-cycle Helium Gas Turbine power conversion system. The first component (the reactor [HTGR]) is developed and is commercially acceptable for use with modern steam turbine plants. Basic technology exists for design and development of the second component, (the Helium Gas Turbine); however, further technological development will be necessary before commercial application can be achieved.

Potential advantages of such a direct-cycle nuclear power plant would be:

- More efficient use of the high temperature capability of the reactor without the temperature degradation that occurs in the steam generator of an indirect-cycle plant
- Simplification by reducing the number of systems and components
- More compact power conversion system due to high-density working fluid in the closed-cycle gas turbine
- Economical adaptability to dry-cooling.
- Incorporation of a secondary power cycle to attain a highly efficient electric generating binary-cycle plant

- Use of rejected heat for water desalinization, district heating, or process heat for the chemical industry.

Combining an HTGR with a direct-cycle Helium Gas Turbine power conversion system could improve plant performance with consequent conservation of financial, fuel, and water resources. A further discussion of the HTGR gas turbine cycle is offered in Appendix H, Exhibit II.

Simple-Cycle Combustion Turbine Improvements

The most modern combustion turbine peaking plants have a thermal efficiency of up to 30 percent. Improvement of combustion turbine efficiency is primarily a function of two parameters--compressor pressure ratio and turbine inlet temperature. High firing temperatures at low pressure ratios result in significant increases in power but do not increase cycle efficiency. With conventional air cooling, efficiency falls off above 2,400°F due to increased cooling air requirements which more than offset the increase in efficiency from higher temperature. For high pressure ratio combustion turbines, higher turbine inlet temperatures yield substantial gains in cycle efficiency. Further gains can be realized through reduced cooling air requirements. Consequently, combustion turbine designs in the 1979-1985 period will emphasize increased firing temperatures with optimum pressure ratios that will benefit both peaking-gas turbine and combined-cycle applications.

Increasing turbine inlet temperatures above 2,400°F will require major changes in both turbine blade materials and cooling techniques. By 1980, improvements in metallurgy and convection air cooling are expected to increase turbine inlet temperatures to about 2,300°F in installed units and by 1985, to about 2,500°F. Efforts to increase temperatures above this level could produce engineering test units with inlet temperatures of 2,800°F to 3,000°F by the mid-1980's. Materials programs include developmental work in ceramic turbine components, turbine blade coatings, claddings, and composite materials. Major cooling developments under way include convection cooling, transpiration air cooling, and water and steam cooling.

The level of nitric oxide (NO_x) emissions (a function of firing temperature) will tend to increase with higher turbine inlet temperatures. Until 1980, combustion technology improvements and water injection techniques will offset NO_x increases due to higher firing temperatures. After 1980, major changes in combustion systems (premixing, catalysts) will come into use.

Combined District/Industrial Heating and Power Generation

Combined district heating and power generation systems have not been constructed extensively in the United States because of the large capital investment required; the historically low cost and availability of primary fuels; and the political difficulties of financing such systems in a free-enterprise economy with strong, autonomous, local governments. These systems have found wider application in Europe where typical district heating power stations are designed to produce only 35 percent of their power as electricity by partially expanding steam in a turbine generator. This steam is then supplied through an extensive piping system to satisfy the basic heating requirements of commercial, industrial, and residential customers.

Based on delivery of both electricity and heating steam, overall power production efficiencies can be as high as 80 percent. One economic estimate made before the recent inflation in construction costs, projected a system cost of $150 per kilowatt of total delivered power. Such systems offer cities some advantages in pollution control and fuel switching. However, their impact in the 1980's will probably be negligible since backfitting an existing city with such a system would be prohibitively expensive. Such systems should be considered for planned new communities which will be developed around new industrial parks.

In addition to combining power generation with district heating, there exists the possibility of combining large utility owned power plants with major industrial facilities requiring large amounts of process steam and electric power. Such a prospect merits consideration because of the significant fuel savings which could result. Opportunities for constructing such complexes are not as numerous as commonly believed as both utilities and industrial firms have criteria other than fuel use which are considered when selecting plant sites.

"On-Site" Generation Systems

Direct consumption of fuel used in supplying the energy requirements of the residential/commercial and industrial sectors may be reduced through installation of systems variously described as "On-Site," "Self-Generation," "Converted Energy," or "Total Energy" systems. The amount of electricity generated by this concept has been small and declining since the 1920's. Extensive utilization would reduce peak and total power generation demands of the electric utility industry. Actual realized savings at any one installation can only be determined by a thorough, detailed analysis of each possibility.

Most reasons for interest in consumer energy conversion systems are related to recent increases in petroleum prices and programs to achieve less dependence upon oil imports. Some other reasons may include:

- Consumer concern regarding the consequences of future voltage reductions and load shedding which could result from announced utility cancellations and delays in construction of new generation capacity.

- Improvement in relative economics for such systems since fuel prices are increasing. The potential higher conversion efficiencies of such systems would make them more attractive. Utilities using fuel oil for power generation have lost most of their volume price purchasing advantage over commercial and industrial customers.

- Government requests for commercial and industrial programs to reduce energy losses are resulting in identification of opportunities for improved energy utilization.

- Government agency demonstration programs (HUD, DOD, etc.) may, if successful, increase interest in such systems.

- Reliability of such systems when properly engineered and serviced.
- A variety of internal combustion and simple-cycle gas turbine system types and sizes can be provided. Small to intermediate sized combined-cycle gas-turbine powered units are developed and may be available prior to 1978.

On the other hand, there are a number of reasons development of such systems may be deferred. These include the following:

- Most systems are based on scarce oil or natural gas fuels whereas utilities can produce energy with coal or nuclear fuel.

- Capital requirements for facilities are shifted from the utility sector to the residential, industrial, or commercial sector. Securing capital funds for these latter sectors may be difficult in the face of severe competition. These funds may be needed for use in the basic business enterprise.

- Such systems may reduce the flexibility of the business to meet expanding or contracting business conditions.

Estimates of the *maximum potential growth* and resultant direct effects of consumer energy conversion systems upon utility power generation are included on Table 17.

Geothermal

Strictly speaking, the significance of the development of the geothermal energy potential in the United States, is not in net energy savings but in the shift of demand to hitherto unexploited energy sources. The total, worldwide, installed, electric-generating capacity using geothermal energy is about 1,197 megawatts (MW), of which the U.S. capacity is 502 MW installed at the Geysers Geothermal Field in California. In the last three years, numerous governmental agencies, private organizations, and individuals have published estimates of total, installed, electric-generating capacity expected from geothermal energy for the year 1985, ranging from 2,400 MW to 132,000 MW. Numerous legal, institutional, environmental, and technical barriers have deterred de-

TABLE 17

POTENTIAL EFFECTS OF CONSUMER ENERGY CONVERSION SYSTEMS UPON UTILITY OPERATIONS AND FUEL CONSUMPTION--1985

	Residential/Commercial			
	Conversion of Existing Sites*	Application to New Construction--1978-1985†	Industrial‡	Total
Installed Generating Capacity (MW)	90,000	14,000	38,000	142,000
Electric Generation (Billion KWH)	550§	87¶	200	837
Utility Central Station Fuel Replacement (Quadrillion BTU's)#	5.95	0.94	2.15	9.04
Incremental On-Site Fuel Consumption (Quadrillion BTU's)	--	--	1.30	--
High Range	1.88	0.29	--	3.47
Low Range	4.70**	0.73**	--	6.73
Energy Conversion Fuel Savings (Quadrillion BTU's)	--	--	0.85	--
High Range	4.07	0.65	--	5.57
Low Range	1.25	0.21	--	2.31

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* Assumes installations equal to 9 percent (500,000) of estimated potential feasible sites through 1977 and average capacity of 2 MW per site.

† Assumes that a maximum of 20 percent of new residential/commercial electric requirements will be supplied by on-site generation systems.

‡ Assumes that self-generation portion (14.7 percent) of industrial section total electric energy requirements will be maintained through 1985.

§ Based on a high assumption of 70 percent utilization of generation capacity.

¶ Based on assumption of a maximum of 20 percent of new residential/commercial electric requirements being supplied by on-site generation systems and Phase I estimate of electric energy portion of 1985 total residential/commercial energy requirements.

Assumes an average transmission loss of 7 percent for central station power transmission and central station heat rate of 10,000 BTU's per KWH in 1985. Average heat rate for industrial self-generation assumed to be as low as 6,500 BTU's per KWH.

**Energy consumption for on-site electricity generation is assumed at 100 percent efficiency for load and is used for the high range. Low range values are at 40 percent of savings and reflect possible imbalance among heating, cooling, and electrical requirements.

velopment of a viable geothermal industry in the United States. Geothermal exploration techniques have been developed to identify localized areas of geothermal potential and have permitted delineation of a number of separate prospective areas, the majority of which are located on federal lands in the western United States.

Although 75 percent of the world capacity is installed at vapor-dominated fields, it is expected that most new geothermal fields discovered and exploited will be of the liquid-dominated type. Despite optimism expressed about the future of geothermal energy, the Geysers Geothermal Field is the only commercial development for electric power generation in the United States. The delay by the U.S. Bureau of Land Management, in both releasing federal lands for geothermal leasing and in processing issuance of leases on those few lands which have been released and bid on, is not only delaying exploratory work on the federal property, but is also slowing the exploration of private lands adjacent to federal properties. Exploration companies holding private land located adjacent to potential federal geothermal lands are reluctant to drill on their limited land holdings. Should high temperature fluids be found, then the adjacent federal lands opened for lease after the fact, could be lost to competitors.

Geothermal energy has its own environmental problems which must be recognized. These include the release of noxious or nuisance gases (e.g., hydrogen sulfide); evaporation of massive quantities of water for plant condenser heat removal and rejection; contamination of ground water systems during withdrawal and injection of geothermal brines; ground subsidence caused by removal of large quantities of water from a reservoir; generation of earth movement when spent brines are injected into faults; and land-use impacts associated with brine gathering and disposal systems.

Obtaining the large quantities of water needed to provide for plant cooling (about 50 to 60 acre feet per year per MW) or to replenish geothermal reservoirs in order to forestall the possibility of ground subsidence is a particularly severe problem in almost all areas where geothermal reserves exist. Due to the low, inherent efficiency of conversion to electricity of geothermal plants, they require as much as three times the cooling water of conventional fossil fueled facilities. The principal geothermal reservoirs found to date have been located in arid regions where water is available at a high cost.

The vapor-dominated, geothermal system (direct-steam cycle) encountered in the Geysers Field presents little difficulty to commercial development; however, such systems are rare in nature. The Imperial Valley region of Southern California contains a large and unusually hot geothermal area known as the Salton Sea Geothermal Field (sometimes called the Buttes Geothermal Field). This field is extremely saline containing almost 30 percent dissolved solids. This high temperature brine causes extensive scaling and corrosion problems in both wells and surface equipment hindering successful development of the field for electric power production.

R&D efforts are being conducted to utilize this high temperature resource, but it is not expected that commercial development will be possible in the near future. Even if it becomes technically possible to control the use of such high temperature saline brines, the cost may be such as to rule out its practical use for electric power generation.

Various federal agencies have been involved in a diversity of projects, each associated with some aspect of geothermal R&D. The Marysville Geothermal Project conducted by the National Science Foundation's Rann Division involved the drilling of a test well near Marysville, Montana, to establish the viability of the "hot dry rock" geothermal reservoir concept. The Atomic Energy Commission's Division of Applied Technology working through Los Alamos Scientific Laboratory drilled two test wells in central New Mexico. This project was also directed toward investigating the possibility for extracting energy from hot dry rock geothermal areas. The U.S. Bureau of Reclamation has drilled six wells and erected experimental test facilities at its East Mesa Geothermal Resources Project Development site in the Imperial Valley to investigate the possibility for commercially desalting geothermal fluids to obtain potable water. These and other government R&D projects have contributed to our knowledge of geothermal resources and potential resource utilization techniques. However, significant work must be completed before a commercially viable geothermal industry comes into existence.

Hydroelectric Power

Hydroelectric power will play a relatively decreasing role in future electric power production, even though its absolute capacity will increase. At present, hydroelectric power contributes 14.5 percent of the electric energy delivered in the United States.* This contribution is expected to decrease to about 5 percent by 1993. However, hydroelectric generation will continue to be an important source of electricity in some geographical regions (e.g., Pacific states) and will be of increasing importance with regard to peaking power. The development of new technology will be directed largely toward increasing generation capacity, using sites with lower heads, and improving construction techniques.

Presently, in the contiguous United States there are 54,885 MW of installed hydropower capacity. By 1983, an additional 11,400 MW capacity will be operating. This includes the 6,878 MW now being constructed. About one-half of the present capacity and 80 percent of that under construction or projected by 1983, will be in the Pacific states. A further 12,204 MW are identified as possible additions between 1983 and 1993. With these increases in capacity, a total of 78,587 MW would exist by 1993, an increase of 43 percent over the present level. The increase in generation between 1974 and 1993 of the additional capacity would amount to 49

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* Federal Power Commission News Release No. 20333, Washington, D.C.: May 24, 1974.

billion kilowatt hours (KWH) per year, or the equivalent of 80 million barrels of oil.*

In addition to these projections, an estimated 38,000 MW of undeveloped potential for hydroelectric generation exists. This excludes sites which would be precluded by being classed as wild or scenic rivers and considers only plants of 25 MW or more. This would result in an additional generation of about 100 billion KWH per year, which is equivalent to burning 160 million barrels of oil. About 32,500 MW of undeveloped capacity exists in Alaska, but full exploitation would require construction of long transmission lines to the contiguous United States.

No major technological changes are projected for the next 20 years, although a number of improvements on existing equipment and sites will take place. The major goals will be to utilize presently marginal sites and to increase the hydroelectric peaking capabilities. One trend in hydroelectric technology will be to increase capacity of existing sites by constructing lower pool afterbays and installing reversible pumps that can be used for both pumping and generating. In addition, larger size units, up to 600 MW, are being installed or projected for use. Other developments involve sites with lower heads in the range of 15 to 35 feet. Axial-flow, tubular-type turbines and bulb units of the type developed in Europe are being installed and proposed for this purpose. Improvements in design and building of dams, and in tunneling and underground excavations are expected to be responsible for increased economies in hydroelectric construction. In connection with this, the use of underground powerhouses for economy reasons and/or site restrictions is expected to occur.†

Distributed Generation and Storage Techniques

Distributed Generation

Dispersed power generation is a nontraditional concept where generating units are located within the distribution network. This results in a reduction of transmission line requirements and of transmission losses in addition to dispersing pollution sources, reducing system reserve requirements, and other benefits.

The fuel cell, the most promising dispersed generation candidate, offers significant energy saving possibilities because of its anticipated low heat rates and high efficiency under partial load. However, the impact of fuel cells on energy consumption prior to 1985 will be minimal. The most probable estimate of maximum fuel cell capacity by 1985 (5,000 MW) produces a conser-

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* Federal Power Commission News Release No. 20293, Washington, D.C.: June 13, 1974.

† Federal Power Commission, *The 1970 National Power Survey: Part I*, Washington, D.C.: December 1971, pp. I-7-1 to 1-7-30.

vatively estimated annual fuel savings of 0.024 quadrillion BTU's. The ultimate market potential has been estimated at 15 percent of new and/or replacement capacity in the intermediate load market. The fuel cell is in the early stages of commercial development and uncertainties remain about the economic viability of the concept as well as fuel supply for fuel cell use.

Distributed Storage

The use of storage at points within the distribution system would allow large efficient fossil and nuclear plants to provide peak power (peak shaving) and intermediate power (load leveling). It would allow the expansion of base load capacity beyond that which would be feasible without storage. The significance of storage is not in net energy savings (typically a 25 percent loss is experienced in the round trip), but in the shifting of demand to more plentiful energy sources. Under one assumed penetration scenario, the savings in fossil fuels is 3 quadrillion BTU's in 1990 and 18 quadrillion BTU's in 2000. Annual impact of distributed storage prior to 1985 must be considered negligible because all forms of storage are in the early stages of development. The equipment closest to practicality is the lead acid battery and even if its utilization were expedited, it is estimated that the fossil fuel savings through 1985 would approximate only 0.3 quadrillion BTU's.

Large Central Energy Storage

Pumped Storage

Presently, pumped storage is the only significant method of storing electric energy at large central sites. Present installed capacity for pumped storage is 8,200 MW and is projected to increase to about 41,000 MW by 1993. A recent report by the Federal Power Commission has identified about 155 sites in the states of California, Arizona, Nevada, and Utah having a potential of 341,100 MW.* These are sites that could be economically developed with existing technology and they range in size from a minimum of 1,000 MW to a maximum of 7,800 MW. The impact of this could be profound in terms of its effect on energy storage and load management. More evaluation is needed to determine the amount of pumped storage that could actually be used considering system requirements, environmental problems, and transmission costs. In addition to the sites identified in the Southwest, the FPC staff has indicated that a potential of similar magnitude exists in the East and surveys are under way to determine such sites.

Since this information is so recent, no efforts have been initiated, as yet, to exploit the potential of pumped storage. The major effort to date on increasing the potential of pumped storage

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* Federal Power Commission, *Potential Pumped Storage Projects in the Pacific Southwest,* Washington, D. C.: 1975.

has been development of underground storage. Because of its minimal surface impact, underground pumped storage is a promising method of off-peak energy storage. The basic need is to improve the economics of such systems by improving construction techniques. Pumped storage for peaking will become increasingly important as fuels for conbustion turbines are depleted. The undeveloped potential recently identified by the FPC offers hope that this efficient, flexible method of energy storage will play a much larger role than previously anticipated. However, as in the case of other forms of electricity storage, the significance of pumped storage is not in net energy savings, but in shifts to more plentiful energy sources.

Compressed Air

Compressed-air storage, like pumped hydroelectric storage, is not an energy saving technique. It is a means of conserving scarce petroleum fuels by shifting much of the energy requirements of gas turbines to off-peak power from nuclear or coal plants. In the air-storage concept, air is compressed in off-peak periods, and the compressed air is stored in underground caverns. During peak periods, compressed air is used in the combustion cycle of gas turbines to increase their electrical output. The advantage of air storage would be the improved fuel economy of gas turbines from around 12 thousand BTU's per KWH to around 4 to 5 thousand BTU's per KWH. (An additional approximate 7.4 thousand BTU's per KWH would be provided during off-peak periods to compress the air, the overall system heat rate would be of the order of 11.4 thousand BTU's per KWH.)

The world's first air-storage peaking plant (290 MW) is scheduled to be installed in Germany in 1977. Studies to define the applicability of the technique to the U.S. plants have recently been initiated. Without the results of these studies, it is impossible to accurately project the implementation of this technology. The earliest estimated date for a U.S. commercial plant is 1983; therefore, the impact of fuel saving prior to 1985 will be negligible.

Burning of Garbage and Refuse

There are several promising methods for generating electricity from recovered energy in refuse. The combustible fraction can be extracted either by shredding or pulping and fed as a supplemental fuel to conventional utility steam boilers. The 70 to 80 percent by weight of municipal refuse which is combustible, replaces about 10 percent of the normal heating energy supplied to the boiler. The net environmental impact compared to incineration, is attractive; the economies often compare favorably with land-fill projects and usually exceed incineration projects.

Prepared trash can also be chemically decomposed to produce an oily liquid or a gas; this fuel can then be burned in steam boilers. Alternately, either the trash or decomposition products can be burned and the hot gases used to power a gas turbine. Widely varying in characteristics, costs, and applicability, several different energy recovery concepts may prove viable. The Environmental Protection Agency has projected a practical potential energy recovery capacity by 1985 of 700 trillion BTU's of fuel, or less than 70 billion KWH of electricity.

Environmental Protection Measures and Their Impacts on Efficiency of Electric Generation

Environmental protection equipment, in many cases, consumes a considerable fraction of power-plant capacity. This is due to the power consumed in operating the equipment and the loss in power plant efficiency by adding the equipment to the power generating system. The loss in power plant capacity must be replaced, in most cases, by less efficient cycling and peaking equipment which consumes additional fuel and may require additional environmental equipment. In some cases, the fabrication, operation, feedstock transportation, and waste disposal for environmental control equipment consumes considerable amounts of energy.

Cooling Towers, Ponds, and Spray Canals

Thermal waste control equipment operates on the latent heat of vaporization and consumes large amounts of water and power as compared to the use of once-through cooling systems. The principal advantage of the thermal waste control equipment or systems such as cooling towers, spray ponds, and lagoons is that they can operate in a nearly closed-cycle mode and do not discharge large quantities of heated water into the environment. The use of closed-cycle cooling water systems consumes additional energy because water must be pumped through the system in large quantities and at high flow rates due to the higher temperature of the recycled cooling water. As this water must be evaporatively cooled, a considerable amount of power is required to operate the fans which drive air through the cooling towers.

Many cooling systems perform most effectively at higher water temperatures. However, this same temperature increase adversely affects the efficiency of the power plant because it causes the steam to condense at a higher turbine back-pressure and increases the turbine heat rate. In some cases, the turbine back-pressure can be so high that pressure drops across the turbine's blades and retards their motion. This causes the turbine to be nearly inoperative and its output must be cut back until the back pressure drops into its output range. This output cutback can cause an efficiency loss of around 5 percent. New power generating systems that were designed to use cooling towers may experience energy savings only slightly higher than the power consumption of the pumps and fans. The turbines are designed to operate at higher cooling water temperatures and any possible increase in efficiency by eliminating closed-cycle cooling systems will be less than 0.5 percent of capacity.

Stack Gas Scrubbers

The Environmental Protection Agency has recently designated the lime/limestone slurry wet scrubber as the best commercially available equipment for eliminating sulfur dioxide (SO_2) from flue gas. These scrubbing systems require the extensive use of pumps, fans, and steam which result in energy losses in the electric generating system. In addition, minor losses are experienced due to auxiliaries and instrumentation, and energy is required to supply and process chemical feedstock for the SO_2 scrubbers. Quantities of lime or limestone feedstock must be transported to the power plant prepared by crushing and grinding and mixed with processed water to form a slurry. After the slurry has been reduced to calcium sulphate or sulphite in the scrubbers, it is then discharged in the form of a wet gelatinous sludge weighing over three times as much as the original feedstock, due to the addition of water and SO_2. This sludge must be impounded and treated in order to prevent it from becoming an environmental hazard. The energy required to dewater, transport, and convert the sludge to an inert substance has not been precisely estimated, as adequate processes have not been developed to perform these functions. Table 18 provides some data to estimate energy losses in lime and limestone scrubbing systems.

From these data it has been estimated that for a typical coal-fired power plant of 500 MW capacity, power to operate the equipment is approximately 3 percent of capacity, steam consumption approximately 3 percent of capacity, and feedstock and sludge handling approximately 2 percent of capacity. Total energy required to oper-

TABLE 18

TYPICAL SCRUBBER REQUIREMENTS FOR 500 MW POWER PLANT
BURNING 3 PERCENT SULFUR COAL WITH AN 80 PERCENT LOAD FACTOR
(Estimated Annual Requirement)

Scrubber	Limestone	Lime
Basic Alkali (Tons)	210,000	95,000
Process Water (Thousand Gallons)	60,000	1,800,000
Power Demand (KW)	8,000	12,000
Power Energy (Thousand KWH)	53,000	82,000
Annual Steam Demand (Million BTU's)	800,000	800,000
Steam Energy (Million BTU's)	620,000	620,000
Sludge Disposal (Tons)	660,000	420,000

ate environmental control equipment for this typical plant is approximately 8 percent of plant capacity. These estimates are not well defined as only a small amount of operating data exists and may be inaccurate due to the limited operating periods.

Chemical Treatment

Chemical treatment of boiling, condenser, and cooling tower blowdown, and cleaning waste water, coal pile run off, and ash pond drainage under present water quality regulations requires less than 0.1 percent of plant generating capacity. The shutdown of this equipment could cause significant environmental damage and provide only small fuel savings. The application of new water effluent regulations which are being considered by EPA could cause additional energy consumption. A case in point is the application of discharge limitations to effluents on a gross rather than a net basis. If the gross basis is used, then all water discharged from the plant may have to be treated so that the discharged water is cleaner than the input water from the source. This is a recent development and no estimate of energy loss has yet been made but it could be on the order of 1 percent of plant capacity, which is about the level of pump and fan losses for cooling tower operation.

Electrostatic Precipitators

The health risk due to particulates has been well documented and the elimination of precipitators does not appear to be justified on a fuel conservation basis. Electrostatic precipitators use only about 0.1 percent of a power generating system's capacity. The retrofit of older mechanical dust collectors, in some cases, increases power generating efficiency if higher capacity draft fans are installed to provide for the higher pressure drop across the precipitator.

Clean Use of Coal Based on Low-BTU Gasification for Producing Electricity

In the future, when burning coal for the production of electrical energy, utilities will have to choose whether to remove undesirable constituents before or after combustion. After combustion, the problem of removing coal ash from the exhaust gases has largely been solved through installation of electrostatic precipitators. Removal of SO_2 from the exhaust gases poses a greater problem. Today there is disagreement within and outside of the utility industry about the adequacy of existing SO_2 stack gas "scrubbing" systems. The adequacy of these devices to meet imposed limits, their reliability, and their cost vary widely at different installations.

In an effort to alleviate these difficulties, engineers have revived attempts to deal with the sulfur content of coal at an earlier stage in the combustion process. Several concepts have been proposed and are in varying stages of development. Many of these concepts produce a clean low-BTU gas by the removal of both undesirable ash and chemical constituents to provide fuel for combustion. One process under development and expected to succeed in large scale applications in the 1979-1985 period is the Lurgi coal gasification process. The Lurgi process accomplishes gasification by reacting coal with air and steam at high pressures. Undesirable compounds can be removed from the gas by several methods and the hydrogen sulfide removed from the gas is usually converted to elemental sulfur for disposal.

In the more distant future, other gasification processes appear attractive. The Lurgi process requires high steam flows which lead to a loss of latent heat from steam passing to the stack. Fluidized bed processes operating at 1,100°C and elevated pressures offer the possibility of complete utilization of all steam, as well as carbon fed to them while avoiding the lower temperature problem of ash adhering to the coal particles.

When comparing processes for the production of low-BTU gas *versus* synthetic pipeline high-BTU gas, it is found that low-BTU gas production is much simpler since oxygen, methanation, and carbon dioxide (CO_2) shift conversion facilities are not required. For low-BTU processes, lower capital requirements, lower operating costs, and higher energy recovery efficiency are predicted. Moreover, direct integration with a power plant will permit recovery of sensible heat. Efficiencies over 80 percent for low-BTU gasification systems are expected. There are steam boiler losses of 5 to 7 percent associated with the use of low-BTU gas in boilers designed for natural gas; some of this loss can be avoided in new units by designing the boiler for lower exit gas temperatures.

As with all methods of generating energy from coal in an environmentally acceptable manner, there are serious waste management problems regarding the removed constituents. The United States lags far behind Europe in the utilization of ash; the major European uses for ash and slag are for concrete aggregates and additives to cements in cement blocks and dam construction. In 1969, only 16 percent of recovered ash was used in the United States for this purpose as opposed to 30 percent in Europe. The United States faces a major disposal problem without better industry utilization of ash. Similarly, the sulfur by-product from coal gasification--power plant combinations may easily be projected to exceed the total U.S. demand for sulfur. Gasification processes also consume large quantities of water with all of the usual heated effluent management problems.

Noise Suppression Techniques

One of the greatest potential sources of community noise is probably the mechanical draft cooling tower which can be controlled by static methods. If land is available for isolating the cooling tower, then the effects on the community would probably be negligible. If the cooling tower is located in a congested urban area, the necessary land for buffer zones may be unavailable and engineered devices such as the acoustic enclosure of pumps, the use of low-speed pumps, and attenuating baffles, may be required. The application of these devices, although expensive, is not energy consumptive except for small losses of efficiency. A further discussion of noise suppression is given in Appendix H, Exhibit III.

Very Long-Term Potentials for Fuel Substitution

Breeder Reactors

One electric generating concept being developed to relieve dependence on fossil fuels is the breeder reactor. Breeder reactors require uranium fuel supplies, as do present light-water reactors. However, only 1-2 percent of the energy potentially available in naturally occurring uranium resources is utilized with light-water reactors. The breeder reactor can utilize 60 percent or more of the total energy available from uranium; thereby, extending usable fuel reserves for hundreds of years.

Reactor technology for the specific form of a fast breeder reactor which has the earliest potential is the liquid metal fast breeder reactor (LMFBR). This reactor utilizes sodium for cooling. The first laboratory scale unit of the LMFBR was constructed in the United States in 1946; the fifteenth unit constructed in the world began in 1974. The largest LMFBR plants operating today are prototype commercial units being developed outside the United States. A similar plant is scheduled for the Tennessee Valley Authority (TVA) electrical grid by 1985. The Gas Cooled Fast Reactor (GCFR) using the thorium cycle has also had significant industry support during the past 8 to 10 years and could be demonstrated soon after the LMFBR. By 1990, the first commercial breeder reactors might be in operation but will make only a small contribution to the generation of electrical energy.

Initial breeder reactor fuel costs should be lower than light-water nuclear fuel costs; LMFBR plant costs, while more expensive initially, may ultimately prove lower because of lower pressure operation of the reactor, higher electrical generation efficiency, and a resulting smaller plant size per unit of electrical output. Conservation of fuel and reduced land disturbance from mining are other major advantages of breeder reactors. Nuclear safety and waste disposal problems are not that different from those of present light-water reactors. Disposal of radioactive wastes from existing nuclear reactors is still the subject of much research and investigation and for the very long term, improved solutions to this problem must be found.

Solar Energy

Solar energy encompasses the following technologies: heating and cooling of buildings, solar thermal conversion to electricity via the Rankine cycle, wind electric energy systems, photovoltaic conversion of sunlight directly into electricity, bioconversion, and ocean thermal gradient conversion. Utility companies are supporting R&D programs in all of these areas. The major problem areas considered crucial from a utility system standpoint are: costs and reliability, integration of solar power plants into the total utility system, and system considerations dealing with storage and back-up energy requirements.

By 1985, solar energy technology will be ready for substitution in only a small fraction of the total U.S. energy requirements. Almost all solar energy will be used for heating of residences (primarily displacing base load electrical heating). A considerably smaller part of U.S. energy requirements will be provided by wind energy systems. Although it is extremely difficult to estimate the rate of introduction of solar systems at this time, a reasonable estimate of fuel savings by 1985 would seem to be an upper limit of 0.25 quadrillion BTU's (0.12 million barrels per day oil equivalent), or less than one-fourth percent of estimated total national energy requirements in 1985.*

Central station generation of electricity via solar-Rankine steam-cycles and direct photovoltaic conversion are unlikely to have any significant impact before the late 1990's. A possible exception to this might arise if a major breakthrough in silicon or cadmium sulphide solar cells were to occur (in which case, perhaps 10,000 MW could be in place by the early 1990's). Without such breakthroughs, it is estimated that in the year 2000, solar energy could supply 2.0 to 2.5 percent of the Nation's total energy needs (almost all coming from solar heating and cooling). See Appendix H, Exhibits IV and V detailed discussions of solar heating and cooling systems, and solar thermal conversion systems.

Controlled Thermonuclear Fusion

Controlled thermonuclear fusion offers potential as an essentially inexhaustible energy source. It is brought about by fusion of light nuclei (hydrogen, deuterium, and tritium) which releases large quantities of energy. For this to occur in a controlled manner so that the nuclear energy can be used to produce electricity, two events must occur: (1) the light nuclei must be heated to temperatures exceeding 100 million $^{\circ}$K in order to overcome their mutual COULOMB repulsion and fuse; and (2) a sufficient number of nuclei must be confined for a long enough time so that a net release of energy occurs.

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* Programs under way or planned by the Federal Government and Electric Power Research Institute (EPRI) will, during the next 3-5 years, provide long-needed technical and economic parameters for each estimation.

Two methods are being pursued to achieve these goals. The first involves confining the plasma (collection of the light nuclei in an ionized state) by interaction with a superimposed magnetic field. Simultaneously, energy is fed in by a variety of schemes to raise the temperature to the point of thermonuclear ignition. To date, the best prospect is the Tokomak device under investigation at five U.S. laboratories. The other method requires the use of powerful laser beams to both compress and heat a solid deuterium-tritium pellet to ignition. The best estimates now available are that the Tokomak will successfully demonstrate production of thermonuclear energy by burning deuterium and tritium by 1982.

Beyond this point, there are vast engineering problems that need to be solved to bring about a successful demonstration reactor. The estimate is that a reactor can be built by 1995. Subsequent to this, a period of 10 to 20 years could elapse before substantial generating capacity utilizing fusion would exist. Therefore, in the 1979-1995 time frame, electricity generated by fusion will have a negligible effect on the Nation's energy supply unless significant breakthroughs occur. There is the possibility that fusion could have an indirect effect, if the concept of the two-component torus (TCT) presently being pursued by the Energy Research and Development Administration (ERDA) is successful. At this facility, a Tokomak is raised to a pre-ignition level at which time additional energy is fed in by a beam of neutral particles (second component of light nuclei). Fusion reactions would occur releasing large numbers of energetic neutrons.

Even at this point a net energy gain would still not occur. However, by using neutrons to breed Plutonium or Uranium$_{233}$ from fertile material, a net energy gain may be possible. Several modes are under study including a pure breeding mode as well as one which breeds and produces power. Such processes would take place under less stringent physics requirements and appear to possess fewer engineering difficulties than merely the production of electricity from fusion. Therefore, the potential exists for impact before 1995. Whether this will occur depends on the systems research and economic feasibility analyses presently under way.

ELECTRICITY TRANSMISSION EFFICIENCY

Alternating Current (AC) Technology

In addressing methods for improving transmission efficiency, consideration should be given to levels of power transmitted, distance transmitted, and annual load factors. On short lines, loss reduction can be achieved by increasing conductor cross-sectional area or bundling phase conductors. On long lines at transmission voltages, loading is determined more by surge impedance of the line than by the thermal characteristics of the conductor. On very long lines, loading is limited to slightly less than surge impedance loading because of difficulties with voltage regulation. (Surge impedance loading is the loading at which the voltages at sending and receiving ends of the line are equal in magnitude and reactive power generation and consumption within the line is balanced. It varies from 50 MW at 138 kilovolts [KV] to approximately 5,000 MW at 1,100 KV.)

Utilization of voltages in the ultra-high voltage (UHV) range will be required in the future to transport very large blocks of power using a minimum number of transmission lines. These UHV circuits will be of the 1,100 KV range and will overlay existing extra high voltage (EHV) systems in a manner similar to the way EHV systems presently overlay lower voltage systems. Existing technology has advanced to where UHV systems can be developed. There is still work to be done on the environmental problems associated with UHV systems. In terms of transmitting very large blocks of power, the capital investment, and the number of rights of way, UHV can now be competitive with lower voltage transmission. Losses in transmitting very large blocks of power are less at UHV than EHV levels. It is estimated that a system using 1,100 KV would have up to five times the savings in transmission losses over a comparable 500 KV system.

Direct Current (DC) Technology

A DC transmission line is more energy efficient than an equivalent AC line, but the extreme cost of the converter/inverter terminals at each end of a relatively short DC line cannot be ignored. Similarly, it would be impossible to utilize exclusively underground cables instead of overhead wires just because the underground system would be more energy conserving. An optimum design must be developed for each energy transmission option where an exact compromise is reached between the cost of energy and the cost of materials. This is what a utility attempts to do in designing its power transmission network. This optimum will conceivably be reached in a normal course of events in a well-planned design program.

This same basic incentive has led to various improvements in overhead and underground AC and DC transmission systems used by the industry today. These improvements have been closely timed with the basic needs dictated by the overall economic conditions at the time these improvements were initiated. If optimized cost is not the common denominator for such improvements, there appears to be no basis for reaching a decision regarding the efficiency of the methods for transmitting electric power. Some theoretically possible ways to reduce losses in transmission systems are:

- Increase the conductor size of the line to provide greater conductivity
- Increase the insulator length to reduce leakage currents
- Convert lines to DC so AC losses can be eliminated

- Move lines underground to take advantage of the inherently lower losses of such systems
- Take the shortest possible routes
- Reduce losses in transformers, capacitors, etc., within substations
- Site generation plants closer to load centers.

High Voltage Transmission as a Competitor of Fuel Transport

Frequently, high voltage power transmission is suggested as an alternative to the surface transportation of fuel. A comparison of the energy required for transportation of energy in the form of coal by slurry pipeline or rail and EHV transmission of power usually reveals that surface modes are generally more energy efficient. Figure 4 indicates that a slurry pipeline of 1,000 mile length consumes less energy than either railroad or EHV transmission. For a 500 mile transport distance, pipeline and rail consume about the same quantity of energy, whereas EHV transmission is still significantly higher. Figure 5 shows the relative cost per ton of the energy used in transportation by the three modes. This comparison shows that a slurry pipeline is the most efficient, followed by rail and then EHV. This is understandable since more than 50 percent of the energy consumed in the pipeline system is coal burned in the slurry dewatering plant. Essentially, all of the energy used in the rail case is diesel oil, while in the EHV case it is electric power. Both cases are based on high-value refined products.

As a base case, (transportation of 25 million tons of coal per year per 1,000 miles) the pipeline system is, from an energy standpoint, 97.4 percent efficient. The comparable figure for a railroad unit train is 96.1 percent, and for EHV is 83 percent. A complete discussion is given in Appendix H, Exhibit VI.

Very Long-Term Developments in Power Transmission and Potential for Energy Conservation

Potential long-term developments in power transmission include the use of cryogenic cables and hydrogen fuel cells. There is little likelihood of utilizing either of these during the Phase II, 1979-1985 period. Discussions of their potentials are given in Appendix H, Exhibit VII.

Distribution Efficiency

The electrical distribution system delivers energy from large transmission system substations to individual customers supplied by the utility. Optimization of the system is complicated because of the variety of small lines and transformers which must be installed

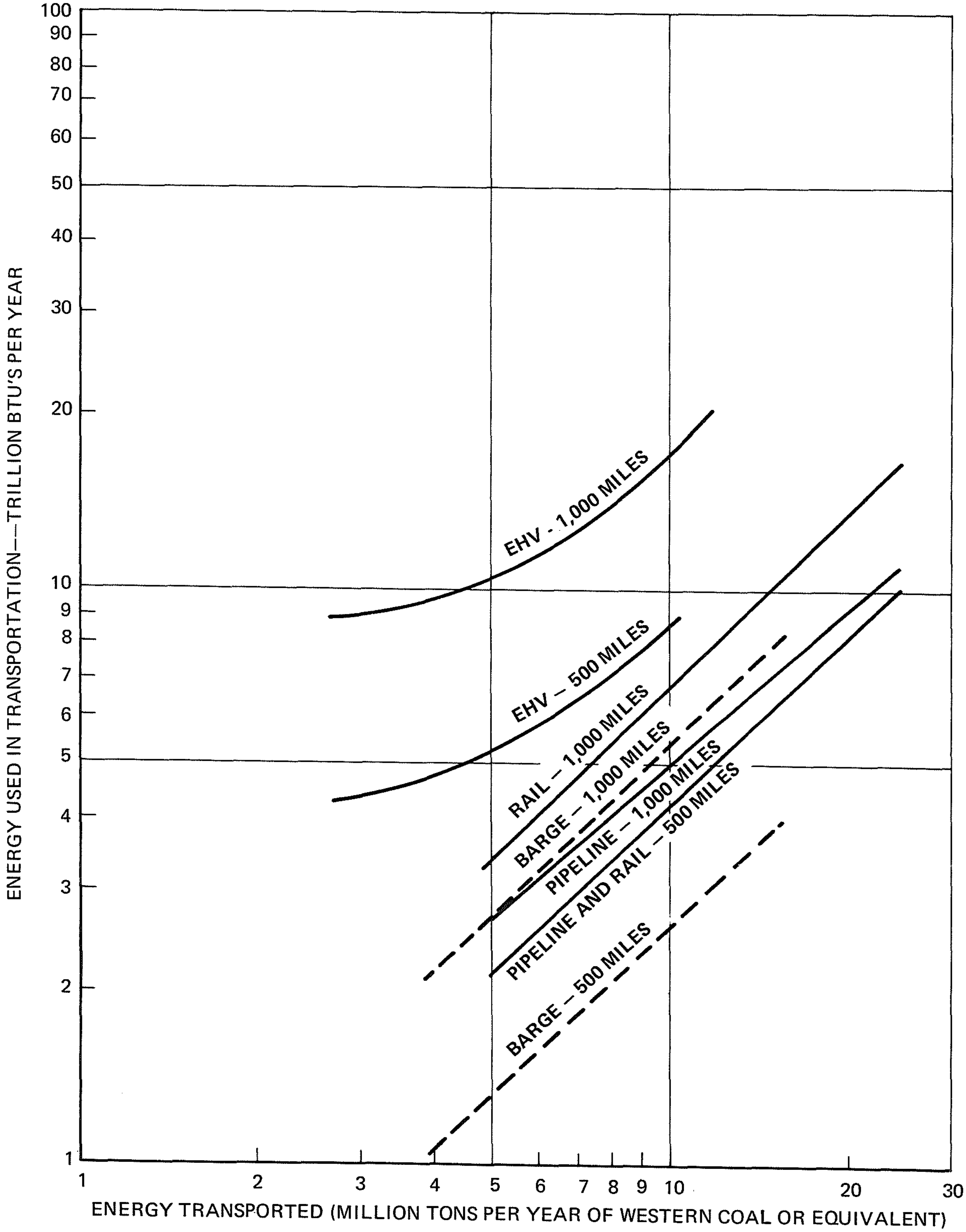

Figure 4. Energy Consumed in Transportation.

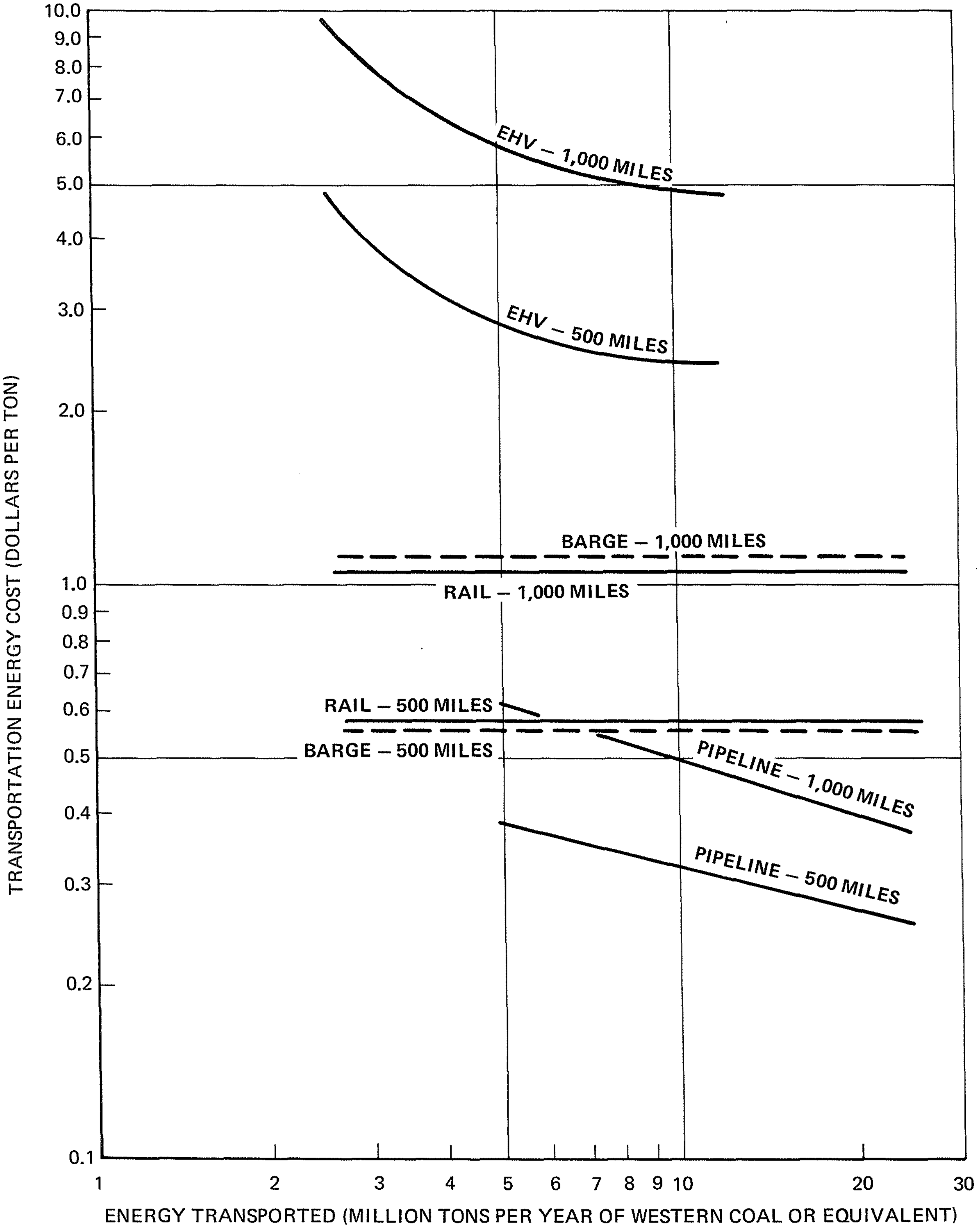

Figure 5. Cost of Energy Consumed in Transportation.

at various times as customer demands change. Inefficiencies result primarily from resistance losses in conductors and iron magnetizing losses in distribution transformers. Possibilities for reducing losses include the use of larger conductors, operation at higher voltage levels, and extension of transmission lines to substations nearer the major load areas. Also, the efficiency of operation of new feeder capacitors and distribution transformers has shown some small improvement because of the availability of better materials. All of these options, however, are more expensive and make larger demands on natural resources such as iron, copper, and land.

Achieving significant energy savings within electric utility distribution systems is unlikely in the foreseeable future. Primarily, this is due to the fact that advance technology for significantly reducing transformer or line losses (e.g. cryogenics) will probably not be applicable to small scale equipment operating at distribution voltage levels. The unit costs of such applications would be astronomical even if technically feasible. Currently, distribution losses average about 5 to 6 percent of total net generation. However, under peak-loading conditions especially during summer, incremental distribution losses may run as high as 20 to 25 percent. Reducing these high incremental losses may be the most promising near-term approach to reducing overall losses.

Methods to reduce peak-period losses entail, for the most part, higher distribution voltages and large capacity transformers. These methods all involve higher total costs, and in many instances, higher unit costs. Fortunately, increasing customer densities and increasing use per customer can help reduce these costs per KWH distributed. The growth in the number of residential customers, the main users of distribution systems, has been averaging more than 2 percent per year and is expected to continue at or near this rate through the mid-1980's. Growth of use per customer has been near 5 percent per year and may remain at this level if electric heating continues its recent rapid expansion.

Another possibility for the reduction of incremental losses during peak periods is the use of energy storage devices in various parts of the distribution systems. These might include batteries, fuel cells, and mechanical systems such as fly wheels. Again, however, capital cost limitations may restrict such schemes to areas of high customer density.

SUMMARY

Through 1985, overall improvement in conversion and transmission efficiency in the electric utility industry is expected to be relatively small in percentage terms. As stressed in several sections of this report, improvements in both steam and internal combustion-cycle efficiencies will probably be offset by additional energy requirements associated with environmental protection measures. However, minor improvements in the net efficiency of the industry represent considerable quantities of primary energy. For example, a 1 percent increase in the current thermal efficiency nationwide would reduce the amount of primary energy required per KWH by about 300 BTU's. Assuming total generation of electricity in 1985 will be between 3 and 4 trillion KWH, such an improvement would mean energy savings of from 900 to 1.2 trillion BTU's, or the equivalent of 410 to 550 thousand barrels of oil per day.

Of various technological advances which could lead to efficiency improvements in the coming 10 to 15 years, the combined cycle (steam turbine/combustion turbine) now appears the most promising. Initially, production units operating on this cycle will require oil or gas as a primary input, but their high conversion efficiencies may justify the use of such fuels. Later, if advanced techniques for coal gasification become available, the combined steam turbine/combustion turbine cycle will supply the means whereby coal can be used in a clean form at relatively high thermal efficiencies. Advanced combined combustion turbine technology could result in cycle efficiencies as high as 50 percent by 1985.

Beyond the potential for conservation of total BTU's, there exists the possibility of displacing considerable amounts of oil and gas. Currently, usage of these two fuels comprises about 30 percent of all primary energy consumed by electric utilities. A vigorous program of coal and nuclear development could permit reduced consumption of oil and gas in the utility sector to as little as 5 percent of total energy requirements by the mid- or late-1980's. Such displacement could result in a level of use in 1985 of about 4 quadrillion BTU's per year, or the equivalent of some 1.8 million barrels per day of crude petroleum. This is a reduction of 1.3 million equivalent barrels of petroleum per day, or 58 percent from the 1974 levels of use. Without coal and nuclear development, however, the electric utility industry will continue to consume these fuels, especially oil, as a significant portion of its primary energy supply. The factor of fuel substitutability is an important subject in the electric utility industry and a discussion of fuel substitution possibilities in the 1980's is given in Appendix H, Exhibit VIII.

Much of the potential for short-term displacement of oil resides in the conversion of existing dual-fired capacity from oil to coal. The Phase I report indicated up to 500 thousand barrels per day of petroleum products could be saved by such conversions.* Additional oil could also be displaced through the employment of pumped storage hydropower as an alternative to combustion turbines for peaking. Other savings in both oil and total energy outlined in the Phase I study would have little significance for the mid-1980's. These latter possibilities related to short-term measures which could be taken prior to 1978 but which did not represent desirable long-term practices (e.g., voltage reductions).

Finally, a cursory review of technological prospects for energy savings beyond the 1980's reveals enormous potential for tap-

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* National Petroleum Council, *Potential for Energy Conversation: 1974-1978*, Washington, D.C.: 1974, pp. 93-102.

ping new energy sources, and some limited prospects for increasing conversion efficiencies beyond projected levels is possible by the late 1980's. Breeder reactors, high temperature gas reactors, geothermal sources, and ultimately fusion reactors may eventually allow electricity production to be derived from fuels with virtually unlimited supply potentials. The widescale use of electricity generated from breeder and fusion reactors could permit significant energy savings in areas such as fuel transport and processing. Exploitation of these advanced options in generation parks could also permit use of excess heat released in the electrity production process for a variety of ancillary purposes with attendant increases in overall efficiency of fuel resource utilization.

Appendices

APPENDIX A

LETTER OF REQUEST

APPENDIX A

United States Department of the Interior
OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20240

In Reply Refer To:
AS-EM

July 23, 1973

Dear Mr. True:

In his energy statement of June 29, the President announced additional steps being taken to conserve America's fuel supplies and their use, and called upon private industry to respond to the energy conservation directives with all the imagination and resourcefulness that has made this Nation the richest on earth.

In December 1972, the National Petroleum Council submitted to me a comprehensive summary report on "U.S. Energy Outlook," the supporting detailed task force reports being now received for each fuel as completed. The results of this exhaustive work done by the energy industries has been of major value to the Department and other agencies of Government, shedding considerable light on the U.S. fuel supply situation in particular.

In order to further assist us in assessing the patterns of future U.S. energy use, the National Petroleum Council is requested to conduct a study which would analyze and report on the possibilities for energy conservation in the United States and the impact of such measures on the future energy posture of the Nation.

You are requested to submit a progress report by January 1, 1974.

Sincerely yours,

Rogers C B Morton
Secretary of the Interior

Mr. H. A. True, Jr.
Chairman
National Petroleum Council
1625 K Street, N. W.
Washington, D. C. 20006

APPENDIX B

COMMITTEE ROSTERS

APPENDIX B

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Transportation Development Division
Highway Users Federation for Safety and Mobility

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Gulf Oil Corporation

APPENDIX C

TRADE ASSOCIATIONS

The following is a list of trade associations to whom this report has been submitted for review and comment:

Air Transport Association of America

The Aluminum Association

American Boiler Manufacturers Association

American Iron and Steel Institute

American Paper Institute

American Society of Heating, Refrigerating and Airconditioning Engineers

American Trucking Associations, Inc.

Association of American Railroads

Edison Electric Institute

Grocery Manufacturers of America

Highway Users Federation

The Hydronics Institute

Manufacturing Chemists Association

Mechanical Contractors Association

Motor Vehicle Manufacturers Association

National Association of Home Builders of the United States

National Association of Motor Bus Owners

National Mineral Wool Insulation Association, Inc.

APPENDIX D

INTRODUCTION AND SUMMARY
REPRINTED FROM
PHASE I REPORT

INTRODUCTION

In the aftermath of recent international events which have led to the Nation's awareness of potential energy shortages, it would appear evident, indeed obvious, that contingency plans must be formulated immediately to provide for the eventuality of recurring shortages. One immediate step toward the solution is to cut back the use of all forms of energy. This report addresses itself to many alternatives for decreasing the use of energy and increasing the efficiency of its utilization: some of these will occur naturally because of increased prices and the scarcity of available energy; some will be achieved voluntarily by the public's response to energy conservation pleas; some will require changes in governmental policy; and others may fall within one of these categories but will be achievable only after extensive research and development and cannot be implemented in the near term. All of these measures have value in that they achieve the goal of energy conservation. However, the answer is not that simple. Reductions are a "must," but it may be difficult to distinguish between essential and capricious uses of energy. Many energy consuming modes and devices which were once considered luxuries have now become integrated into consumption patterns and, at least for the short term, may be classified as essential uses unless other trade-offs are recognized and accepted by the public.

Price plays a major role in the consumer's perceived value of adopting a conservation measure. Given the significant increases in the price of energy over the past year, reinforced by the threat of a scarcity of supply, the consumer or other user has adopted different perceptions of energy values. Although there is insufficient field information to determine accurately price/demand elasticities, demand levels of the past few months definitely indicated that there has been some lessening in demand as a function of price.

There is a significant problem in assessing the real impact of conservation measures because they are a mixture of responses including, but not limited to, market clearing prices, threat of scarcity and ethical concern about the level of energy usage. Given the market as it is comprised, it is impossible to identify what degree of conservation will occur naturally as a result of price. Thus, it is very difficult to determine what options are feasible and what actions should be taken to reduce energy consumption. While energy conservation is important and essential, any program must be integrated into other national goals, such as economic growth, social well-being and environmental clean-up. For instance, programs such as the Clean Air Act of 1970, the federal highway system and certain zoning regulations, all conflict with energy conservation. The impact of these programs on the goals of the Nation must be carefully evaluated before making any trade-offs.

Whatever policy decisions are made, they should *not* erode the public's freedom of choice in selecting options. Energy consumption patterns are so regionalized that an all encompassing policy is

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Editor's Note: Appendix D is reprinted from *Potential for Energy Conservation in the United States: 1974-1978*, Washington, D.C.: September 10, 1974, pp.1-12.

certain to create hardships for certain sections or segments of the Nation and the economy.

The concept and policy of energy conservation must involve a substantially different outlook concerning energy use on the part of the individual than on that of the United States as a whole if it is to be effective. Present use patterns have evolved over a period of years within a framework of economics and incentives that today are rapidly changing or outmoded. What is important is the realization that our present energy environment is different than that of the past and will probably continue to move even further from the previous norms.

The following discussion is predicated upon energy conservation as defined within the following parameters: (1) measures that increase the *efficiency of utilization* of energy without affecting the services provided and (2) measures that *reduce the consumption* of energy by reducing the level of services provided.

The United States is now experiencing a shortage of domestically produced, environmentally acceptable fuels. One reason for this shortage is the increased rate of energy demand growth since the mid-1960's, coupled with the simultaneous slowdown of domestic supply expansion, which resulted in an increasing inability to meet unrestricted demands with available indigenous supply. The outcome has been a rapidly increasing dependence on foreign oil supplies, a situation which was brought into sharp focus by the Arab oil embargo of October 1973.

As vital as energy is to the Nation, the public has been generally unaware of potential energy shortages and the need to conserve energy resources prior to the Arab oil embargo, even though warning signs appeared for many years. Despite the actual shortages experienced during the embargo, some responsible individuals have adhered to the belief that no real disparity exists between supply and potential demand. However, the facts adequately support the growing concern over energy shortages within the United States.

Domestic oil production currently supplies about two-thirds of the Nation's oil demand, and domestic production is declining. Gradual integration and the increased use of other sources of energy into and by the distribution and consumption system have encountered social and environmental problems and thus delays. Consequently, an energy balance distortion has evolved, because of which the Nation is becoming, indeed has become, increasingly dependent on foreign-based supplies to fulfill its requirements. In the future, maintaining a healthy national economy, full employment and reasonable environmental standards will require national goals and priorities on energy which include both conservation and expansion of domestic energy supplies.

The foregoing observation does not imply any lack of natural energy resources within the United States--they are still abundant. The problem inherent in the expansion of domestic energy supplies is, however, one of finding economically feasible and environmentally acceptable ways of locating, developing and utilizing such resources, and of introducing them into existing supply, distribution and consumption channels. Such ways must be found.

Restoration of a more appropriate balance between U.S. domestic energy demand and energy supply will require conservation and an awareness and acceptance of a "conservation ethic" by the American public. But, energy conservation alone is incapable of restoring such a balance. Only a comprehensive national energy policy incorporating *all* aspects of supply and demand considerations is capable of doing so.

The actual magnitude of energy conservation achieved will depend on prices and, furthermore, on the rate of development of additional sources of energy and on the inter-substitutability of fuels, which in turn will depend on policies, laws, regulations and government actions at all levels, particularly that of the Federal Government. The higher price of energy generally has caused a major increase in the number of options to expand energy supplies. Similarly, there are now a large number of economically rational responses on the demand side. It now *pays* to use energy more efficiently, and perhaps to modify our energy life-style.

SUMMARY

Any meaningful discussion of energy conservation must be predicated upon an understanding by the public of how energy is supplied and distributed to individual consumers. Discussion of the acceptability or desirability of energy conservation measures must be based on--in fact, depends upon--public awareness that there is a common need or motivation to curtail inefficient consumption of energy at all levels. Conservation associated with denial or with the substitution of less desirable goods or services will generally elicit a negative public response. However, conservation can and should also carry the connotation of more efficient and economic usage of energy entailing change in utilization patterns.

Excessive energy consuming patterns and the substitution of energy for manpower have been encouraged by various governmental policies and by a changing economy and society. This evolving change in consumption patterns, however desirable or undesirable, has been intensified by extensive advertising and other programs aimed at promoting energy consumption in a wide variety of forms.

Growing energy consumption can be directly related to the substantial changes that have evolved in the life-style of our Nation. Productivity in industry has increased with the growing substitution of machines for labor, resulting in fewer man-hours and shorter working weeks. Alternative activities now consume the time formerly spent at work, and living patterns of the American worker have changed drastically. Migration from inner cities to the suburbs has taken place. New transportation patterns have evolved, as have new consumer buying habits. All of these factors have contributed to the unprecedented growth of this country's economy and, importantly, the level of energy consumption in the United States.

ENERGY CONSUMPTION AND DISTRIBUTION PATTERNS

Based on current levels of technology, energy for Americans is mainly associated with and related to crude oil products, natural gas and coal. Hydropower, geothermal, solar energy and nuclear energy have contributed to a much smaller extent.

Historically, the production of energy in the United States has been a function of private industry under our free-enterprise system. However, government has become involved to the extent that the private sector is now overlaid with a complex set of legislation and regulations ranging from tariffs and fiscal policies to intervention by regulatory bodies of various kinds. Public institutions control, in often conflicting ways, such diverse issues as price, environmental degradation, safety, consumer protection and industrial concentration. The supply side of the energy sector has evolved into a classic example of a "mixed" private/public economy. The demand side of the energy sector differs in that historically there has been less government involvement and a lower level of general public concern.

It is difficult to find evidence of an energy policy relating various government actions one to another. However, throughout our history of public involvement in energy matters, there has been, with certain notable exceptions, a general reliance on private-market solutions and on a belief that low-cost energy is good for the health and growth of the economy. Energy supply and demand in respect of any energy form have rarely been a focus of public interest.

FINDINGS

Analyses of potential energy conservation measures or procedures in the immediate short-term period through 1978 were carefully developed by the end-use sector task groups--Industrial, Residential/Commercial, Transportation and Electric Utility. The evaluations developed by these study groups are briefly stated below.*

Industrial

Seven industries--iron and steel, aluminum, chemical, petroleum, agriculture and food processing, paper and automobile manufacturing--accounting for approximately 75 percent of the energy used by U.S. industry in 1972, were evaluated by the Industrial Task Group. The results are presented in the following appraisal:

- Increased fuel costs and potential shortages are the most important incentives for industry to conserve. Savings evolving from this awareness will result primarily from conscious energy management programs which include existing operations, new equipment and process designs.
- Scrap recycle in the metal industries is an important and significant source of energy savings. At some levels, government policy and foreign trade relations may be in conflict with increased recycling.

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* *Editor's Note: Aggregation of Energy Conservation Potential.* The following sections present estimated future energy savings. However, the reader is cautioned against attempting to aggregate these estimated savings for the purpose of arriving at an overall savings potential for the Nation. The assumptions made, the options available and the ranges of estimated savings set forth are either interdependent or mutually exclusive and, therefore, nonadditive in any meaningful way.

- Constraints in achieving energy conservation goals are the limitations on availability of capital and technical manpower and the restrictions of environmental standards.

- One major area common to most industries is steam generation and use. Emphasis should be placed on more efficient *total system design* such that the maximum work output is captured.

- In the 1974-1978 period, at least an average 10-percent savings in energy usage *per unit of output* can be accomplished in the industrial sector. The percentages vary from 5 to 20 percent, depending on the industry evaluated. Intensification of programs designed to exchange information and technology throughout all industries could effect greater energy savings. This exchange is especially important to those highly decentralized small-scale industries where technical manpower and expertise may be lacking, and in certain industries, such as agriculture, where there are many independent units. Within this portion of the industrial sector, independent identification of more efficient energy utilization is difficult to accomplish.

Residential/Commercial

Although higher energy prices will result in actions to conserve energy, a nationwide energy conservation program coupled with a high level of communication is needed to obtain broad, continuing savings in this sector.

Of the two broad subdivisions of the residential sector--existing construction and new construction--existing construction consumes about 98 percent of all residential energy and is, in the short term, the area of greatest energy conservation potential. The three areas offering greatest potential for near-term energy savings, together with examples of specific action, are:

- Living Habits/Life-Styles

  --Lower thermostat setting in heating season

  --Higher thermostat setting in cooling season

  --Lower water heater temperature

- Insulation

  --Ceiling insulation

  --Weatherstripping and caulking

  --Storm doors and storm windows

- Heating/Cooling
  - --Furnace tune-up
  - --Air conditioner tune-up.

In the new construction market, revisions in building codes are needed to improve energy efficiency in new residences.

In the commercial sector, two conservation actions would account for more than one-half of the potential savings achievable by 1978. These are:

- Maximum temperatures in the heating season of 68°F in apartments and hotels/motels, and 65°F in other establishments (hospitals and nursing homes excepted) during occupied hours
- Temperatures of 5°F and 10°F below maximum heating season temperatures during unoccupied hours.

Given adequate financial incentives, such as low-interest loans and investment tax credits, a high level of implementation of conservation actions requiring investment by residential and commercial owners can be expected.

Transportation

In the transportation sector, the areas offering major conservation opportunities for potential savings, in stated relative order of importance, are:

- Highway (Passenger Cars)
  - --More small cars
  - --Increased car-pooling
  - --Modified exhaust emissions and gasoline regulations
  - --Improved auto design
  - --Reduced speed limits
  - --Improved vehicle maintenance.
- Airways
  - --Reduced flights to increase load factor
  - --Improved operating efficiencies.

Some of the energy savings in these areas will result from increased energy prices, others from voluntary action, and still others will require new or revised regulations.

Total railway, waterway, mass transit, pipeline and other miscellaneous transportation uses account for less than 20 percent of the energy consumed by the transportation sector, thus offering a more limited potential for energy conservation over the short term.

Mass transit systems will not contribute significantly to conservation in the near-term period. Evaluation of such systems should commence immediately in order to have longer-term effect.

Individual choice in transportation should be maintained, but a compromise must be effected wherein the individual motor fuel-burning unit becomes more efficient and at the same time the individual exercises more judicious choice in the utilization of the unit.

Electric Utilities

Under the most strenuous energy conservation efforts, savings in fuel used for electric power generation in 1978 could equal some 5 percent of the 1972 energy used for power production. A major part of these savings would depend largely on substantial changes in exsiting laws and regulations.

About half of the potential fuel savings would depend on elimination of the proposed requirement for closed-cycle cooling. The remaining possible contributors to potential energy savings in descending order are:

- Deferring requirements for stack gas sulfur scrubbing systems.
- Optimum use of the most efficient power generation equipment.
- Modification of new loss of coolant safety regulations governing nuclear plants, voltage reductions and peak load shifts.

Increases in the price of primary energy will decrease the consumption of electricity in the consuming sectors but will have only a small effect on the efficiency of electrical generation by 1978.

If all coal/oil convertible capacity were switched to coal, annual oil savings in 1978 could be 40 to 50 percent of oil consumed by electric utilities in 1972.

PRICE/DEMAND CONSIDERATIONS

Optimal reduction of energy demand growth will result from market responses to price increases; clearer and more stable market signals on supply and demand with less market distortion due to certain public policies; incentives and disincentives to encourage less energy intensive practices; and a broader public awareness of the need for conservation (i.e., a national "conservation ethic").

Results of the calculations in response to the FEO request for a consideration of two cases of increased prices--an instantaneous increase in real primary energy cost of 100 percent and 150 percent over 1970 price levels but occurring in 1974--are presented in Table 1.* This table estimates the reduction in energy consumption that would result from these price changes. Energy conservation opportunities reducing demand patterns and improving the efficiency of energy utilization are more broadly explored by the end-use sector task groups.

TABLE 1

1978 ESTIMATED END-USE CONSUMPTION RESPONSE TO INCREASES IN THE PRICES OF PRIMARY ENERGY*—COMPARISON OF ACTUAL 1972 CONSUMPTION AND 1978 PAST TRENDS—CONTINUE BASE CASE†

			Percent Change In Consumption				
				100 Percent Primary Price Increase		150 Percent Primary Price Increase	
	Consumption (Quadrillion BTU's)						
End-Use	1972 Actual	1978 Past Trends-Continue	1978 Past Trends-Continue *Versus* 1972	*Versus* 1972	*Versus* 1978 Past Trends-Continue	*Versus* 1972	*Versus* 1978 Past Trends-Continue
Residential	10.5	12.8	+21.9	+15.2	–5.5	+13.3	–7.0
Commercial	6.2	7.9	+27.4	+21.0	–5.1	+19.5	–6.3
Industrial	21.9	25.4	+16.0	+ 9.1	–5.9	+ 6.4	–8.3
Transportation	17.8	21.8	+22.5	+15.2	–6.0	+12.4	–8.3
Electric Conversion	13.1	19.8	+51.1	+42.0	–6.1	+38.2	–8.6
Nonenergy	3.7	5.7	+54.0	+48.6	–3.5	+45.9	–5.3
Total	**73.2**	**93.4**	**+27.6**	**+20.4**	**–5.7**	**+17.6**	**–7.8**

*See *Primary Energy Costs, ibid.*

†Past Trends-Continue base case is based upon continuation of historic trends of energy consumption pre-October 1973 embargo and assumes no increase in real energy costs. This represents one of many possible U.S. energy futures that might have occurred if the oil import shortfall and rapidly increasing energy price situations of late 1973 and early 1974 had not occurred.

Note: Based on Chapter One, Table 2.

FURTHER OBSERVATIONS AND COMMENTS

The appraisals of the end-use sector task groups, as well as the data developed by the Patterns of Consumption/Energy Demand Task Group, when viewed individually or as a whole, suggest certain general comments relevant to the formulation of a national energy conservation program for the 1974-1978 time period. The following

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* *Primary Energy Costs, ibid.*

list of such general comments also includes reflections of the Consumer Task Group:

- There will definitely be some reduction in demand as a result of higher energy costs, especially in those areas where costs are monitored closely--i.e., in the industrial and commercial sectors. In other sectors--e.g., private transportation and residential--the response will be slower and more dependent on programs educating the consumer in ways to accomplish energy conservation and monetary savings. Such programs should be sponsored both by government and industry.

- Widespread consumer response to energy conservation programs will only be elicited and sustained when there is a conviction that there is equity in the sharing not only of the "shortages" but also of the burdens of additional costs.

- In the short term and for an indefinite period, energy conservation must be considered an essential component of a national energy policy. On the other hand, the implication that energy conservation alone can overcome the supply/demand gap is unrealistic. Without the continued and accelerated development of domestic supplies of energy, the shortfall in energy supply within the United States will continue and grow.

- Recently proposed research and development programs, particularly within the public sector, concentrate on increasing energy supplies, and rightly so. However, there is also a need for a significant level of research and development effort on the end uses of energy and on more efficient ways of utilizing energy. A partial list of possible areas of inquiry would include land-use planning, housing types and consumer preference, transportation modes and systems, and building codes and standards.

- Public policies in conflict with energy conservation should be re-examined. Such policies would include, but are not limited to:

  --Federal Power Commission regulation of interstate sales of natural gas

  --Some Interstate Commerce Commission regulations on transportation

  --Utility rate structure

  --Funding of highway systems in preference to mass transit

  --Building codes and regulations.

- Careful evaluation of the costs to public health and welfare and to the environment should be included in any consideration of relaxation in or deferral of environmental standards.

- The marketplace has long been the most efficient allocator of scarce supplies. While distortions are occasionally imposed upon the market by external events, such as the recent Arab oil embargo or government intervention, the system should be allowed to clear the inefficient uses of energy and should only be supplemented by public policy decisions when and if there are obvious and untenable inequities in the sharing of the burdens which may be involved.

CONCLUSIONS

National Goals and Policy--Energy and Conservation

Events in late 1973 and early 1974, as related to the energy posture of the United States, have again demonstrated the necessity for a national energy policy which must include balancing energy conservation and other national interests. Government has been active in many areas relating to energy policy; however, there is still no national energy policy interrelating the various government energy actions taken so far.

The development of a balanced national energy policy by the Federal Government, including conservation as a major component, remains urgent. Additional components of such a policy include the continued and accelerated development of domestic supplies, the formulation of realistic environmental clean-up objectives and the equitable and rational distribution of total energy costs. Such a policy must be balanced against the Nation's goals and policies relating to economic growth, full employment, social well-being and, to an increasing extent, foreign policy.

APPENDIX E

INDUSTRIAL

Exhibit I

FOOD PROCESSING INDUSTRY

TABLE 19

MEMBRANE CONCENTRATION OF LIQUID FOODS
(Energy Required per 1,000 Gallons of Desalted Sea Water)

Desalinization Processes	1964 Technology Thousand BTU's	1964 Technology KWH	Estimate For 1980 Technology Thousand BTU's	Estimate For 1980 Technology KWH
Processes Using Heat				
Multi-Stage Flash Distillation	1,020	300	610	180
Long-Tube Vertical Distillation	1,020	300	610	180
Processes Using Electricity				
Electrodialysis	250	25	150	15
Vapor Compression Distillation	610	60	360	35
Freezing	610	60	360	35
Reverse Osmosis	510	50	310	30

Note: Technology used in desalinization of sea water is applicable to membrane concentration of liquid foods (see "Food Processing Industry," Chapter One).

Source: Spiegler, K.S., ed., *Principles of Desalinization*, Academic Press, 1966.

TABLE 20

MICROWAVE DRYING PROCESSES

Moisture Content (Percent)	Cut Vegetable Products	Onions
Initial	30	35
Final	5	4.5
Energy Required for Drying (BTU's per Pound of Water Removed)		
Conventional Air Drying	45,000	45,000
Combined Hot Air-Microwave System	2,135	2,170
Hot Air Portion	1,416	1,632
Microwave Portion	719	538

Exhibit II

HIGH CONSISTENCY FORMING

Fibers suspended in water have a tendency to flocculate i.e., to form local coherent networks. It is generally accepted that these networks are mainly a result of the collision and mechanical entanglement of fibers in a turbulent shear field. The two most important factors contributing to the flocculation of the fibers are the stiffness and length-to-radius of the fibers. When the turbulence subsides, individual fibers assume fixed positions (in the new network) by coming to rest against neighboring fibers before they have regained their unstrained shapes. This flocculation, which is undesirable in conventional paper making, is utilized in the high consistency paper forming process.

HIGH-CONSISTENCY FORMING (HCF) PROCESS

Instead of trying to prevent flocculation, the HCF process facilitates this phenomenon to the highest possible degree, and in such a way, that a continuous matrix of fibers is developed in a specially designed headbox. A large number of fibers per unit volume is required to develop such a matrix, i.e., the concentration must be high. Flocs in the pulp suspension must first be dispersed to allow the individual fibers to assume new positions in a more homogeneous and continuous matrix. This implies that relatively high shearing forces must be generated within the headbox. Once the new matrix has been formed, all disrupting forces must be avoided. It is this homogeneous matrix of fibers that forms the sheet of paper after it has been compressed.

It is obvious that this high consistency forming process is quite different from the conventional method of making paper from low consistency pulp. The sheet of paper is formed already within the headbox and not on the wire as it is in the Fourdrinier process. The similarity with an extrusion process is apparent. Compared with the more modern twin-wire formers,the HCF headbox can be regarded as a former in its own right.

A sheet formed at high consistency can be expected to have a felted and porous structure. The low drainage resistance of such a structure will make it easier to dewater the sheet on the wire and in the press section. It is also known that the rate of drying is higher for a porous sheet. All these factors will reduce energy requirements considerably.

The Swedish Forest Products Research Laboratory reports that the first commercial installation of its high consistency forming process was due for start up in Finland in January 1975. Although they expect a significantly lower power consumption for the wet end of the paper machine, they will only be in a position to report actual energy savings, once the Finnish installation is evaluated.

Exhibit II

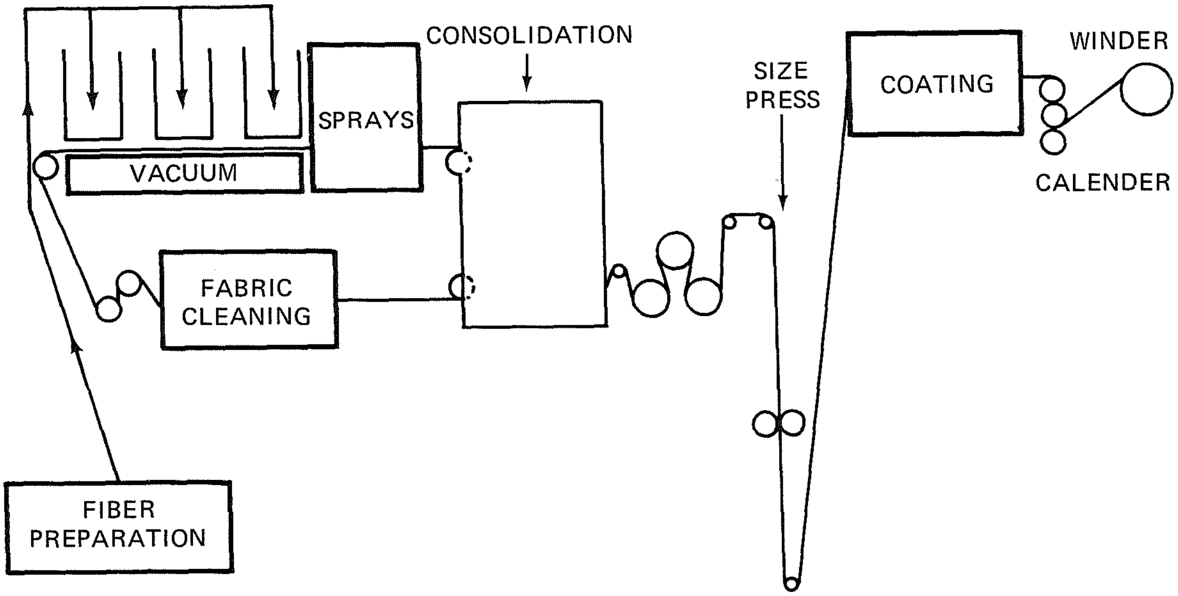
The felted structure should give the paper some unique mechanical properties. The z-strength (i.e., the strength perpendicular to the plane of the sheet) should be exceptionally high. The resistance to compressive failure will therefore also be high because of the low tendency to delaminate. It can also be expected that the sheet will leave the press section with a comparatively well preserved bulk.*

With regard to high consistency forming in particular, there are indications that sheet strength in the plane (tear) is lower than that for paper manufactured in the low consistency process. However, high consistency formed paper does not show much higher strength perpendicular to the plane of the sheet (burst).

An additional problem may be in the finding that there is poorer retention of filler materials such as clay in high consistency as compared to conventional paper making.

DRY FORMING

The material that follows describes a prototype commercial dry-forming machine at St. Anne's Board Mill Co., Ltd., England. Figure 6 is a diagram of the basic principles employed for producing paperboard type materials by a dry method.



SOURCE: Dr. Bryan W. Attwood, "Dry Forming Developments at St. Anne's Board Mill Co. Ltd., *"Proceedings of the 108th Conference,* October 23-24, 1974.

Figure 6. The Dry Forming Process.

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*This section on the mechanics of high consistency forming has been excerpted from a report prepared by K.J. Gundstran, B. Norman, and L. Reimer of the Swedish Forest Products Research Laboratory, Stockholm, Sweden.

Exhibit II

In brief, the fibrous raw material is first dry defibrated by means of suitable equipment such as a hammer mill. Any necessary chemicals can be added in dry form at this stage. The fiber/air suspension is transported to units which distribute the fibers evenly across the width of a forming wire or fabric. Each of these dispensing heads constitutes a "ply." The fibers are sucked down onto the fabric by means of suction boxes situated under the fabric (associated with each battery of three dispensers is a vacuum box). At the same time, there is a circulation of approximately 10 percent of unscreened fiber back to the hammer mill.

The formed web can be lightly compressed by heated rolls arranged in the fabric run, after which the web is treated with an aqueous spray containing any necessary auxiliary materials. The web then passes to a zone in which consolidation of the base web takes place. The remainder of the machine is used to modify the base web in order to give it the desired characteristics. Equipment such as a size press, in-line coaters and associated driers are used. The machine terminates with a single calendar stock and wind-up stand.*

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*This section on the mechanics of dry forming has been excerpted from a report prepared by Bryan W. Attwood, Technical Department Manager, St. Anne's Board Mill Co., Ltd., Bristol, England.

APPENDIX F

RESIDENTIAL/COMMERCIAL

APPENDIX F

ENERGY USE INCREASE IN THE COMMERCIAL SECTOR

CALCULATIONS

As stated in the beginning of the Residential/Commercial Chapter, the Past Trends-Continue case energy demand projections associated with three or more family dwelling units were reallocated from the residential to the commercial sector for this examination. Table 21 shows the calculations reallocating the energy used by the apartment type (3 family and over) dwelling units. This table also shows the calculations allocating electric conversion losses (projected in the Past Trends-Continue case) to apartments and commercial buildings. At the bottom of Table 21, the cumulative totals (including conversion losses) are listed by period for the commercial sector in quadrillion BTU's.

Table 22 provides a more detailed breakdown and summation of the incremental increases in energy use in the apartment and commercial building categories. The upper half distinguishes total BTU increases between fossil fuels, electricity, and conversion losses associated with the generation of electricity, as well as the total incremental increases in the sector for the periods 1979-1980, 1981-1985, and 1979-1985.

The compound annual growth rates, shown on the bottom of Table 22 for the period 1972-1985 is 5.38 percent and 1979-1985 is 5.18 percent.

ENERGY CONSERVATION TECHNIQUES

Tables 23 and 24 list the three categories of energy conservation techniques (building envelope, building systems, and self-imposed actions) and relates their estimated effect on commercial buildings and apartments separately by end-uses of energy listed at the top of each column. For example, the design of the envelope of a building determines its resistance to heat loss or gain. Opposite the building envelope category on Table 23 are figures indicating that a 15 percent reduction in energy use can be realized in the heating and air conditioning requirements of all commercial structures (apartments are evaluated on Table 24) if the structure is designed with conservation as a prime requisite. This figure includes many factors such as glass area, building orientation, etc. This same procedure of assigning various values for techniques was followed under building systems and self-imposed practices. All figures on Tables 23 and 24 are conservative with respect to industry claims.

The Table 25 matrix depicts total fuel and electricity energy increases by building type. It is assumed that changes would occur in the volume of construction in the various building types between 1972 and 1985. In the Phase I report matrix, representing 1972 conditions, each building type was assigned a percentage of the total energy used by the commercial sector. For this examination, these percentages were reapportioned to reflect an increase or decrease in the future volumes of construction in certain categories. Hospitals were increased by 20 percent, supermarkets and stores by 10 percent, and schools and colleges were reduced to balance the total. These changes are reflected in the figures on Table 25. Under the category of stores, the first column indicates that 22 percent of all fossil fuel and 34.3 percent of the electric energy used in commercial buildings was utilized in stores. These totals are then broken down into their various end-uses. At the bottom of Table 25, the energy used in each end-use category, broken down by type of energy is totaled.

TABLE 21

INCREASE IN COMMERCIAL SECTOR ENERGY CONSUMPTION--1978-1985
(Quadrillion BTU's)

	1978	1980	1985
Commercial Sector (Excluding Apartments)			
Calculation of Electric Conversion Loss:			
Total Conversion Loss (All Sectors)	19.8	22.7	30.1
x Percent of Loss Attributed to Commercial Sector	23.84%	24.34%	24.90%
= Commercial Sector Conversion Loss	4.720	5.525	7.496
Commercial Sector Energy Demand (Excluding Electric Conversion Loss)	7.9	8.6	10.6
Apartments			
Calculation of Electric Conversion Loss:			
Total Conversion Loss (All Sectors)	19.8	22.7	30.1
x Percent of Loss Attributed to Residential Sector	34.4%	34.4%	33.7%
x Percent of Residential Estimated to be Apartments	20.9%	21.9%	22.3%
= Total Apartments Electric Conversion Loss	1.424	1.710	2.262
Calculation of Apartments Energy Demand (Excluding Electric Conversion Loss):			
Total Residential Energy Demand	12.8	13.6	15.5
x Percent of Residential Estimated to be Apartments	20.9%	21.9%	22.3%
= Apartments Energy Demand	2.675	2.978	3.457
Cumulative Total Energy Demand (Commercial Sector and Apartments)			
Commercial Sector Conversion Loss	4.720	5.525	7.496
Commercial Sector Energy Demand	7.9	8.6	10.6
Apartments Conversion Loss	1.424	1.710	2.262
Apartments Energy Demand	2.675	2.978	3.457
Total Energy Demand	16.722	18.814	23.815

Note: Based on Table 1, "Parameters of Study" section. Totals may not add due to rounding.

TABLE 22

INCREASE IN COMMERCIAL SECTOR ENERGY CONSUMPTION TRENDS--1978-1985
(Quadrillion BTU's)

	Incremental Increase in Consumption					
	End-Use Electricity	End-Use Fossil Fuel	Total End-Use	Electric Conversion Loss	Total Electricity	Total Energy
Commercial Sector (Excluding Apartments)						
1979-1980	.340	.360	.700	.804	1.144	1.504
1981-1985	.880	1.120	2.000	1.971	2.851	3.971
1979-1985	1.220	1.480	2.700	2.775	3.995	5.475
Apartments*						
1979-1980	.123	.181	.304	.286	.409	.590
1981-1985	.247	.231	.478	.552	.799	1.030
1979-1985	.370	.412	.782	.838	1.208	1.620
Total Commercial Sector†						
1979-1980	.463	.541	1.004	1.090	1.553	2.094
1981-1985	1.127	1.351	2.478	2.523	3.650	5.001
1979-1985	1.590	1.892	3.482	3.613	5.203	7.095

Note: Based on Past Trends-Continue case, Table 1, "Parameters of Study" section.

* "Apartments" calculated at 21.9 percent of residential sector energy use for the 1979-1980 period and 22.3 percent of residential sector energy use for the 1981-1985 period.

† Compound annual growth rates calculated as follows:

	1985 Total Consumption		Base Period Consumption		Base Period/1985 Consumption Ratio		Compound Annual Growth Rate
1972-1985	23.815	÷	12.051 (1972)	=	1.9762	=	5.38 Percent per Year
1979-1985	23.815	÷	16.722 (1979)	=	1.4241	=	5.18 Percent per Year

TABLE 23

POTENTIAL SAVINGS IN COMMERCIAL SECTOR ENERGY CONSUMPTION--NEW CONSTRUCTION 1979
(Percent)

Areas of Conservation	Water Heating		Heating		Air Conditioning		Lighting	Other		Building Class
	Electric	Fossil	Electric	Fossil	Electric	Fossil	Electric	Electric	Fossil	
Building Envelope	0	0	15	15	15	15	0	0	0	All
Building Systems										
Heat Pump (Electric)	0	0	40	0	0	0	0	0	0	All
System Design	15	15	30	30	30	30	0	5	5	All
Higher EER	0	0	0	0	20	0	0	0	0	All
Heat Reclaim Refrigeration	60	60	60	60	0	0	0	0	0	Supermarkets
More Efficient Light Fixtures	0	0	0	0	0	0	15	0	0	All
Self-Imposed Actions										
Reduce Lighting Levels	0	0	0	0	0	0	25	0	0	All
Temperature Management*	5	5	20	20	20	20	0	0	0	All

Note: Apartments not included (see Table 24).

*Assumes a 5°F reduction in space heating, a 5°F thermostat setback at night and on weekends, and a 5°F increase in cooling temperatures.

TABLE 24

POTENTIAL SAVINGS IN APARTMENT PORTION OF COMMERCIAL SECTOR ENERGY CONSUMPTION--NEW CONSTRUCTION 1979

(Percent)

Areas of Conservation	Water Heating		Heating		Air Conditioning		Lighting	Other	
	Electric	Fossil	Electric	Fossil	Electric	Fossil	Electric	Electric	Fossil
Building Envelope	0	0	15	15	15	15	0	0	0
Building Systems									
Heat Pump (Electric)	0	0	40	0	0	0	0	0	0
Higher EER	0	0	0	0	20	0	0	0	0
Higher Equipment Efficiency	0	10	0	10	0	0	0	0	0
More Efficient Light Fixtures	0	0	0	0	0	0	15	0	0
Self-Imposed Actions Temperature Management*	5	5	20	20	20	20	0	0	0

---

*Assumes a 5°F reduction in space heating, a 5°F thermostat setback at night and on weekends, and a 5°F increase in cooling temperatures.

TABLE 25

TOTAL INCREASE IN FOSSIL FUEL AND ELECTRIC ENERGY CONSUMPTION BY BUILDING CATEGORY AND END-USE--1978-1985

(Quadrillion BTU's)

	Percent per Building Category	Space Heating	Air Conditioning	Water Heating	Lighting	Other	Total
Apartments							
Fossil Fuel	--	.319	0.0	.069	0.0	.024	.412
Electric End-Use	--	.237	.018	.050	.012	.053	.370
Gross Electric*	--	.770	.060	.162	.042	.174	1.208
Stores							
Fossil Fuel	22.0	.270	.023	.031	0.0	.001	.325
Electric End-Use	34.3	.118	.184	.015	.083	.018	.418
Gross Electric*	--	.388	.602	.049	.272	.059	1.370
Schools							
Fossil Fuel	18.8	.237	.004	.036	0.0	.001	.278
Electric End-Use	10.9	.047	.037	.008	.034	.007	.133
Gross Electric*	--	.154	.121	.026	.111	.023	.435
Supermarkets							
Fossil Fuel	10.1	.134	0.0	.014	0.0	.002	.150
Electric End-Use	15.1	.081	.036	.009	.027	.031	.184
Gross Electric*	--	.266	.118	.029	.088	.102	.603
Hospitals							
Fossil Fuel	12.6	.141	.006	.039	0.0	.001	.187
Electric End-Use	9.8	.037	.049	.011	.008	.015	.120
Gross Electric*	--	.121	.162	.036	.026	.048	.393

(Continued)

TABLE 25 (CONT'D.)

TOTAL INCREASE IN FOSSIL FUEL AND ELECTRIC ENERGY CONSUMPTION BY BUILDING CATEGORY AND END-USE--1978-1985

(Quadrillion BTU's)

	Percent per Building Category	Space Heating	Air Conditioning	Water Heating	Lighting	Other	Total
Offices							
Fossil Fuel	8.5	.108	.007	.010	0.0	.001	.126
Electric End-Use	11.5	.045	.056	.005	.024	.010	.140
Gross Electric*	--	.147	.184	.017	.079	.032	.459
Hotels							
Fossil Fuel	7.6	.091	.004	.017	0.0	.001	.113
Electric End-Use	6.8	.026	.032	.006	.014	.005	.083
Gross Electric*	--	.084	.106	.019	.045	.017	.271
Colleges							
Fossil Fuel	5.9	.071	.003	.012	0.0	.001	.087
Electric End-Use	3.0	.011	.016	.002	.007	.001	.037
Gross Electric*	--	.036	.052	.007	.023	.003	.121
Other							
Fossil Fuel	14.5	.175	.002	.036	0.0	.001	.214
Electric End-Use	8.6	.044	.024	.009	.019	.009	.105
Gross Electric*	--	.144	.079	.029	.062	.029	.343
Total							
Fossil Fuel	100.0	1.546	.049	.264	0.0	.033	1.892
Electric End-Use	100.0	.646	.452	.115	.228	.149	1.590
Gross Electric*	--	2.110	1.484	.374	.748	.487	5.203

Note: Total commercial sector energy consumption increase is 7.095 quadrillion BTU's.
*Includes conversion losses from generation of electricity.

APPENDIX G

TRANSPORTATION

Exhibit I

HIGHWAYS--PASSENGER CARS AND LIGHT TRUCKS

CARPOOLS

In 1972, the typical vehicle use mix for each 1,000 nontransit work trips is given on Table 26. This mix requires 6,665 vehicle miles per 1,000 trips.*

TABLE 26

NONTRANSIT WORK TRIP VEHICLE USE--1972
(Per 1,000 Trips)

	Vehicle Trips	Persons per Car (Average)	Person Trips
	525	1	525
	131	2	262
	31	3	93
	24	4-6	120
Total	711	1.41	1,000

The typical vehicle use for 1,000 trips that can be achieved by 1978 is given on Table 27. With this vehicle use the average carpool loading would be increased to 3.0 persons per car and carpools would account for 65 percent of all trips.

The 1978 vehicle use mix requires 5,614 vehicle miles per 1,000 trips including 0.4 miles added travel for each new carpool trip. This expanded use of carpools would reduce work trip travel 15.7 percent over the 1972 level.

By 1985 with carpools carrying 75 percent of all nontransit work trips and carpool occupancy increased to 4.0 persons per car by the use of vans, the vehicle use mix given on Table 28 would be typical.

The 1985 mix requires 4,260 vehicle miles per 1,000 trips including 0.4 miles added travel for each new carpool trip and 1.5 miles for each van pool trip. This expanded use of multiple occupancy vehicles would reduce work trip travel 24.1 percent over the 1978 case and 36.1 percent over the 1972 level.

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* Derived from information reported in the *National Personal Transportation Study*, U.S. Department of Transportation.

Exhibit I

TABLE 27

NONTRANSIT WORK TRIP VEHICLE USE--1978
(Per 1,000 Trips)

	Vehicle Trips		Persons per Car	
	No Change	New Carpools	(Average)	Person Trips
	350		1	350
		16	2	32
	33		2	66
		113	3	339
	31		3	93
	24		4-6	120
Total	567		1.76	1,000

TABLE 28

NONTRANSIT WORK TRIP VEHICLE USE--1985
(Per 1,000 Trips)

	Vehicle Trips		Persons per Car	
	No Change	New Carpools	(Average)	Person Trips
	250		1	250
		69	2	138
	28		2	56
		12	3	36
	35		3	105
	17		4-6	85
		33	10	330
Total	444		2.25	1,000

55 MPH SPEED LIMIT

Studies in 27 states in 1974 showed that traffic on Main Rural Roads had slowed down, and 85 percent of the free moving vehicles were traveling at 61 miles per hour (MPH) or less. In 1972, on these same roads, 85 percent were traveling at speeds up to 70 MPH. The distribution of the 1972 and 1974 travel on these roads by 5 MPH increments is given on Table 29.

The "normal 55" distribution given on Table 29 is the usual compliance with a 55 MPH speed limit (85 percent of vehicles trav-

Exhibit I

eling at or less than 55 MPH). It is assumed that by 1985 the combination of continued enforcement of the 55 MPH limit and increased public acceptance of its need will result in rural travel at the "normal 55" speed distribution.

Using the fuel consumption curve representative of the current mix of vehicles--the relative change in total fuel consumption for travel on the Main Rural Roads between 1972, 1974, and 1985 (assuming a "normal 55" speed distribution) can be determined. The fuel consumption values used in this analysis are given in the following tabulation.

Miles per Hour	Under 40	40-45	45-50	50-55	55-60	60-65	65-70	Over 70
Gallons per Mile	.0505	.0505	.0515	.0540	.0565	.0615	.0655	.0700

TABLE 29

DISTRIBUTION OF TRAVEL IN EACH SPEED INCREMENT
(Percent)

	1972	1974	Normal 55 MPH
Under 40 MPH	2	3	4
40-45 MPH	4	5	13
45-50 MPH	10	16	31
50-55 MPH	14	29	37
55-60 MPH	20	30	12
60-65 MPH	19	12	3
65-70 MPH	17	4	--
Over 70 MPH	14	1	--

Exhibit II

HIGHWAYS--COMMERCIAL TRUCKING

IMPROVED VEHICLE DESIGN--STREAMLINING

The following is a discussion of the National Science Foundation's "Research Applied to National Need" program in aerodynamic research and of devices that could achieve fuel conservation in the motor freight industry. One of the devices being considered is a "simple shape" which is attached to the sharp corners on the front of a trailer body or straight truck, and is designed to reduce engine power wasted in overcoming air resistance. Another unit is a streamlined housing device which fits on the trailer and partially fills the gap between tractor and trailer. This is the area which presents one of the most difficult problems regarding aerodynamic drag. While the fuel saved by the use of these and similar devices currently being investigated could prove to be substantial, there are some legal and/or economic considerations which arise and must be solved before the fuel savings actually becomes a reality.

When a device is installed along the front of the cargo container, no problem is generally encountered provided the additional weight of the add-on device is not substantial. However, if the device is installed on the top front and/or top side of the truck body or trailer, the vehicle generally exceeds the height and/or width limits specified by law. This approach to drag reduction will only work on standard rectangular straight trucks or trailers. It is not designed for use on specialized equipment such as tank or flat bed trailers.

The "Bull Nose" device which is attached to the front of a trailer partially fills the gap between the tractor and trailer. Use of this device can present legal and economic problems since a number of states specify the maximum trailer length allowed within the confines of its borders. For example, if the maximum legal trailer length in a given state is 45 feet and a "Bull Nose" device is attached, lengthening the trailer, then some states would be forced to find the trailer in violation of the law. Even though this additional length is attached to the front of the trailer, and does not increase the total vehicle combination length, longer than is currently allowed, it is still considered in violation of the law. law.

When "Bull Nose" devices are designed into the truck or trailer to keep within the legal width, length and height restrictions of the law, cargo capacity is reduced. Reducing the cargo capacity of a vehicle also reduces freight revenue. This amounts to a loss of approximately $2.20 per year per pound of payload displaced. This is a reduction in productivity that should not be ignored, especially in times of inflation and recession. The amount and cost of the fuel saved by these devices must be weighed against several off-setting factors: the loss of cargo per vehicle; the loss of freight revenue per vehicle; the cost of an extra vehicle (including the fuel it consumes); the expenses of an additional driver; and the cost of facilities required to handle the same amount of freight.

Another possible problem with streamlining vehicles is the added maintenance and labor costs that could be encountered, if these factors are not given proper consideration in the streamline design. An example of an experiment undertaken in this area is one by the Ryder System. The experiment has reported "outstanding results" on preliminary tests of a new tractor design. Air drag is reported to be "significantly less than other tractors in their fleet," and although no specific figure on fuel savings is given, a "very appreciable" gain was indicated. Also, preliminary studies at Texas A&M University have concluded that modifications to the ends of tank trailers could be beneficial in reducing aerodynamic drag.

Exhibit III

URBAN PUBLIC TRANSIT

TABLE 30

URBANIZED AREAS OF THE UNITED STATES WITH POPULATIONS OVER 1 MILLION--1970

Area	Population (Millions)	Density (1,000 People per square Mile) Total	Density (1,000 People per square Mile) Central City	Fixed Rail System
New York-New Jersey	16.2	6.6	26.3	Yes
Los Angeles-Long Beach	8.4	5.3	7.0	No
Chicago-Northwest Indiana	6.7	5.3	15.2	Yes
Philadelphia-New Jersey	4.0	5.4	15.2	Yes
Detroit	4.0	4.6	11.0	No
San Francisco-Oakland	3.0	4.0	11.0	Yes
Boston	2.7	4.0	13.9	Yes
Washington-Maryland-Virginia	2.5	5.0	12.3	Under Construction
Cleveland	2.0	3.0	9.9	Yes
St. Louis	1.9	4.1	10.2	No
Pittsburgh	1.8	3.1	9.4	No
Minneapolis-St. Paul	1.7	2.4	7.1	No
Houston	1.7	3.1	3.8	No
Baltimore	1.6	5.1	11.6	Under Construction
Dallas	1.3	2.1	3.3	No
Milwaukee	1.3	2.7	8.0	No
Seattle-Everett	1.2	3.0	6.4	No
Miami	1.2	4.7	9.8	No
San Diego	1.2	3.1	3.6	No
Atlanta	1.2	2.7	3.9	Under Construction
Cincinnati-Kentucky	1.1	3.3	5.9	No
Kansas City	1.1	2.2	3.9	No
Buffalo	1.1	5.1	11.2	No
Denver	1.0	3.6	7.6	No
San Jose	1.0	3.3	3.7	No

Source: From printed material accompanying a speech by Former Secretary Claude S. Brinegar, Department of Transportation, at a Scientific American Round Table Discussion, March 17-18, 1974.

Exhibit III

NET MOTOR FUEL SAVINGS FROM AN ADDITIONAL 100 THOUSAND URBAN BUSES

Assumptions:

a. Average car occupancy (To and from work) : 1.6

b. Average car miles per gallon : 13.1

c. Average bus load factor : 13.3

d. Average bus miles per gallon : 4.0

e. Number of additional buses : 100,000

f. Average annual miles per bus : 31,500

g. Passenger miles shifted from cars to buses* : 41.9 billions

---

* Bus load factor × average annual miles per bus × number of buses (i.e., 13.3 × 31,500 × 100,000).

Calculations:

Since "average car occupancy" is defined as $\frac{\text{Passenger miles}}{\text{Vehicle miles}}$ the passenger miles diverted from cars can be converted into vehicle miles by:

$$\text{Vehicle miles} = \frac{\text{Passenger miles}}{\text{Average car occupancy}} = \frac{41.9 \times 10^9}{1.6}$$

$$= 26.2 \text{ billion miles per year}$$

Fuel savings from not using cars are thus:

$$\text{Fuel savings} = \frac{\text{Vehicle miles}}{\text{Miles per gallon}} = \frac{26.2 \times 10^9}{13.1}$$

$$= 2 \text{ billion gallons per year}$$

$$= 130 \text{ thousand barrels per day}$$

Exhibit III

These fuel savings must be reduced by the fuel used by the additional buses which is:

$$= \frac{\text{Number of buses} \times \text{Average annual miles}}{\text{Miles per gallon}} = \frac{100{,}000 \times 31{,}500}{4.0}$$

= 787.5 million gallons per year

= 51.4 thousand barrels per day

Net motor fuel savings are thus 130 minus 51.4 or 78.6 thousand barrels per day.

APPENDIX H

ELECTRIC UTILITY

Exhibit I

MAGNETOHYDRODYNAMICS (MHD)

Thermodynamically, energy is extracted from an expanding fluid in an MHD machine by reducing the temperature and pressure and increasing the volume of the fluid as in a conventional expansion turbine. In most applications today, the fluid is operated at a sufficiently high temperature so that it becomes ionized (a condition known as a plasma). Electrically, it is a conductor and its motion is directed through a magnetic field. This causes a current to flow in a direction which is mutually perpendicular to both the motion and the field as in any other piece of electrical machinery. This current is collected and directed to an external electrical circuit where it can perform the variety of tasks. One device serves both functions and is therefore classified as a direct conversion machine.

Today, extensive programs are under way throughout the world with most of the effort concentrated in the United States, Japan, and the U.S.S.R. Research projects have as their aim the augmentation of theoretical understanding or the development of components (e.g., long-life channels and efficient burner systems for direct firing of coal or other heavy hydrocarbon fuels). Alternatively, simplified gasifiers to effectively use these "dirty" fuels are also being explored. Other areas of research include:

- Air preheaters capable of furnishing compressed combustion air at temperatures of 3,000°F or more.
- Channels which can withstand the rigors of a 4,500°F or higher seeded plasma at near-sonic velocities.
- Electrodes and electrode coatings which can interface with this plasma and effectively receive or supply high currents from the plasma without propensity to short-circuit or otherwise fail.
- Seed removal systems which can remove virtually all the entrained seed, a necessity for economic operation as well as pollution control.
- Means for effective waste heat recovery, a necessity since the energy content of the exhaust gas is high, engendered by the need to expel exhaust at a temperature conducive to good conductivity.
- Development of superconducting magnets, both as a necessity for producing high magnetic fields and as an economic necessity for reducing the energy consumption of conventional field winding.

Exhibit II

HIGH TEMPERATURE GAS COOLED REACTOR (HTGR)/ CLOSED-CYCLE GAS TURBINE SYSTEMS

The closed-cycle gas turbine has been used for the last 30 years (mainly in Europe), in fossil fuel-fired plants for electrical power generation combined with district heating. Nine fossil-fired closed-cycle gas turbines with outputs ranging up to 30 Megawatts (MW) are in service. The fundamental difficulty that has hindered development of the closed-cycle gas turbine for use with fossil fuels resides in the means for transferring chemically produced heat into the cycle, requiring a heat exchange surface operating at temperatures even higher than the peak working fluid temperature, and facing simultaneously the problems associated with corrosion by combustion products. Nuclear power eliminates this problem altogether by permitting direct heating of the clean, noncorrosive working fluid.

The Gas Turbine High Temperature Gas Cooled Reactor (HTGR) power plant is an integrated design with the reactor, turbomachinery, heat exchangers, and the entire helium inventory contained in a Prestressed Concrete Reactor Vessel. One proposal for a 1,100 MW plant includes three paralleled power conversion loops. The turbomachinery in each loop consists of a multi-stage gas turbine, and a multi-stage axial compressor mounted on a horizontal-single-shaft with a 3,600 revolutions per minute (RPM) generator.

The following are some objectives which should be considered in the planning stage for plant designs:

- Safety features affording prompt licensability
- Required electric generating plant availability, maintainability, durability, and ease of operation
- Most economical overall plant design consistent with the first two objectives.

The incentives to combine a HTGR with a direct-cycle Helium Gas Turbine power conversion system come from improved plant performance with consequent conservation of financial, fuel, and water resources. The dry-cooled Gas Turbine HTGR plant is 36 percent efficient; the wet-cooled binary cycle Gas Turbine HTGR is 44 percent to 46 percent efficient. The benefits derived include:

- Energy Conservation

  --The Gas Turbine HTGR would offer improved and economic utilization of nuclear fuels and realize savings of fossil fuels.

- Electric Power Generation Economics for 1,100 MW Plants

Exhibit II

--For a dry-cooled Gas Turbine HTGR plant, generation cost is 23 percent less than for a dry-cooled Light Water Reactor plant and 12 percent less than for a wet-tower cooled Light Water Reactor plant.

--For a wet-tower-cooled HTGR steam-cycle plant and a dry-tower Gas Turbine HTGR plant, generation costs are nearly identical.

--For a dry-cooled Gas Turbine HTGR plant, generation cost is 12 percent less than for a dry-tower cooled HTGR steam cycle plant.

--For a binary cycle Gas Turbine HTGR plant, generation cost is 14 percent less than for the HTGR steam cycle plant for equal 1,440 MW rated plants.

- Water Conservation

--For a dry-cooled Gas Turbine HTGR plant, zero water consumption provides essentially unlimited siting flexibility.

--For a wet-cooled binary cycle Gas Turbine HTGR, high plant efficiency minimizes reject heat and reduces thermal pollution.

Exhibit III

ENERGY IMPACT OF NOISE SUPPRESSION TECHNIQUES

The Walsh-Healy Act and the Occupational Safety and Health Act (OSHA) provide a legal definition of what constitutes potentially hazardous noise levels in industrial environments, and sets limits to the noise exposure of workers in these environments. These limits are shown on Table 31.

TABLE 31

OSHA PERMISSIBLE SOUND LEVELS

Daily Exposure (Hrs.)	Sound Level Slow Response (dBA)	Optional Octave Band Sound-Pressure Levels (dB)							
		63	125	250	500	1,000	2,000	4,000	8,000
8	90	110	103	97	91	88	86	86	87
6	92								
4	95	128	116	106	98	92	89	83	92
3	97								
2	100		125	115	106	99	94	93	99
1-1/2	102								
1	105		135	127	116	107	100	98	105
1/2	110		135	135	125	115	107	104	112
1/4	115		135	135	132	121	112	110	119

Source: Occupational Safety and Health Act of 1970.

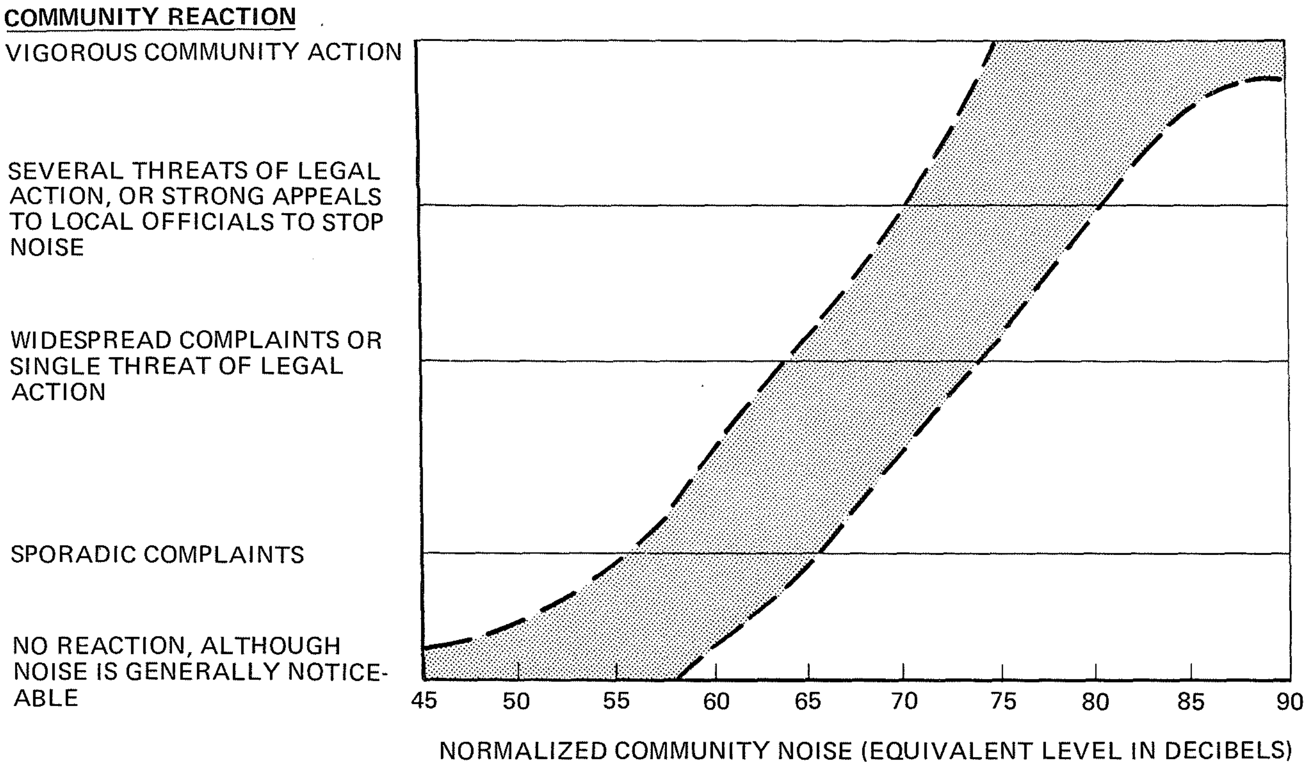
The sound pressure levels shown on Table 31 must be attained by the designers of the power plant in order to protect employees. The designs include acoustically engineered rotary equipment, and vibration isolation to prevent structure borne sound and re-radiation as airborne sound to the exterior of the plant. These methods usually depend on sound absorption and attenuation which do not consume much energy. The principal exception to this case is the gas turbine generator which may be located very close to a community so that mufflers and resonators may be used to dynamically attenuate the noise and vibrations. However, the mufflers for typical gas turbines (GT) cause efficiency losses of about 0.2 percent and, as the GT is typically used for peaking or cycling, the energy loss would be quite small.

The Noise Control Act (NCA) of 1972 was passed by the U.S. Congress in recognition of the need to deal with noise as an emerging environmental problem of national concern. While the Occupational Safety and Health Act of 1971 dealt with the noise problem

Exhibit III

as related to workers, the NCA was designed to protect the health and welfare of the community from differing amplitudes, quantities, and qualities of noise.

The Environmental Protection Agency (EPA) is primarily concerned with the control of noise from interstate carriers and with the source emission control of noise from products. The states and their subdivisions have the responsibility of determining the noise levels which are acceptable to the community, but the EPA was given the responsibility to assist local governments in determining these levels. Figure 7 illustrates the sound pressure levels which citizens find objectionable or acceptable.



SOURCE: Frank L. Cross, Jr., Assessing Noise Impact on the Environment, *Pollution Engineering,* November 1973, p.52.

Figure 7. Common Community Reaction to Intrusive Noise.

Exhibit IV

SOLAR HEATING AND COOLING SYSTEMS

Experimental investigations of solar heating concepts and facilities span a period of more than 40 years. Early facilities included the Massachusetts Institute of Technology (MIT) solar house begun in 1930, a small home begun by Dr. George Lof in 1945, and the recent Thomasson home. System concepts have ranged from active liquid-to-air to air-to-air heating with storage, to simple circulating water systems such as the Harold Hay, Skytherm concept. Nearly all of these concepts are based on a flat-plate collector to convert solar energy into thermal energy.

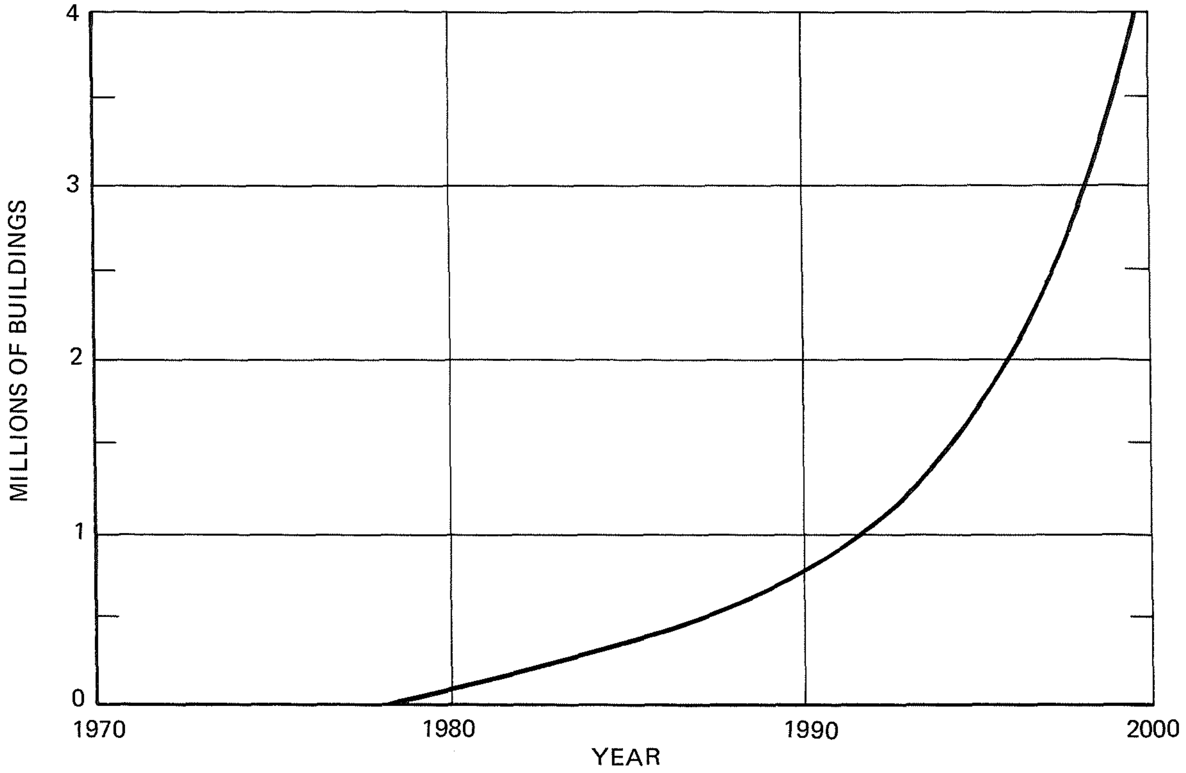
The basic development and analysis of the flat-plate collector was done by Hottel & Woertz with more recent efforts presented by Whillier. Early economic analyses on solar heating for individual residences presented by Tybout and Lof covered a broad span of climatic regions of the United States; parametric variations in factors such as collector tilt angle; relative storage capacity; and collector size. All analyses were evaluated in order to recommend the most cost effective system. Subsequent analyses were extended to include solar heating and cooling systems.

These analyses showed that solar flat-plate collector installed costs of $2 to $4 per square foot were required if solar heating and/or combined heating and cooling systems were to be competitive with alternative energy sources. Higher fuel costs may allow collector costs up to $6 to $8 per square foot in specific situations. The requirement to manufacture, market, and install solar collectors in this price range is still the single most important aspect associated with solar heating and air conditioning (SHAC) system utilization.

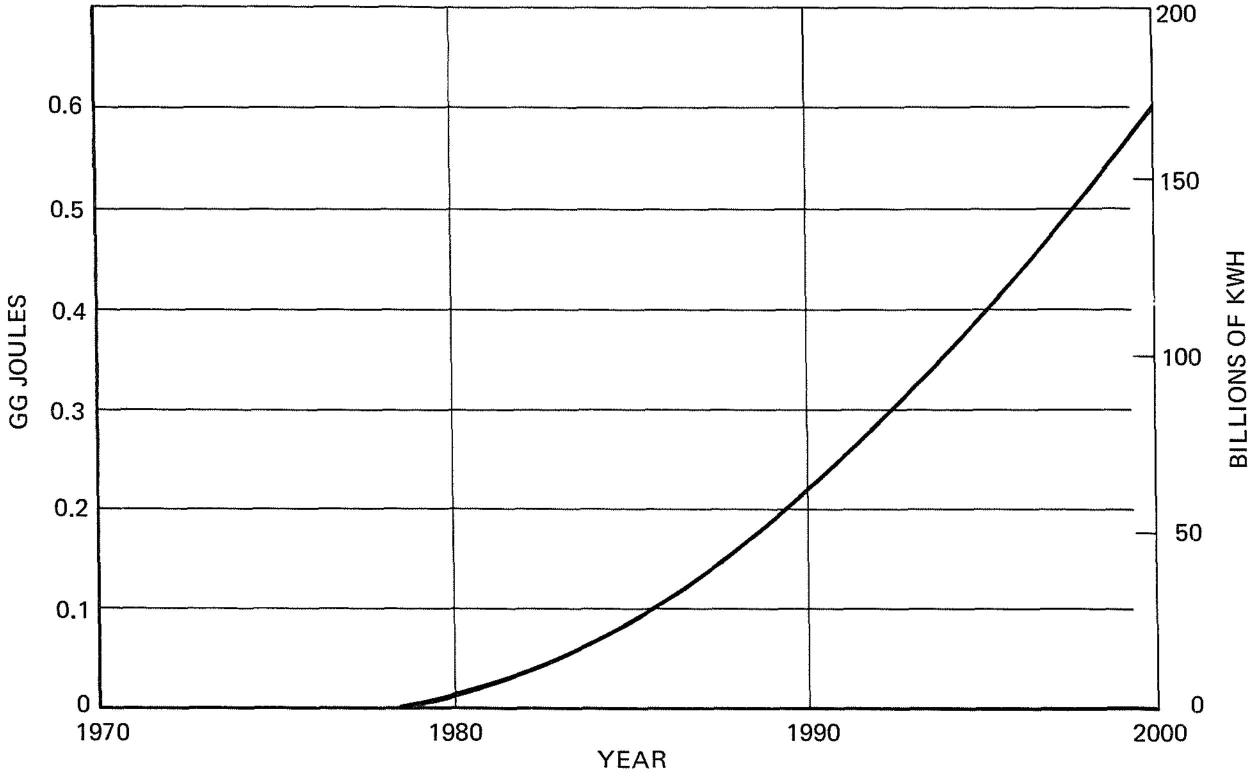
To date, a broad range of system, subsystem, and component concepts have been studied for SHAC applications. Solar heating efforts are being concentrated on direct utilization of the thermal energy collected (or via a storage system) or solar assisted heat pumps. Recent study results indicate that solar space heating should be competitive with electric heating in the southwestern, northeastern, and portions of the southeastern and midwestern parts of the country on an energy displacement basis (see Figure 8).

Solar collector units are currently available with a nominal price range of $10 to $20 per square foot. These typically have roll-bond aluminum or steel absorber plates with nonselective or low selectivity, black coatings and two layers of glass (or plastic) glazing materials. Control of the working fluid's acidity and use of inhibitors is generally recommended to minimize corrosion tendencies. Experience with recently deployed solar collectors indicates that copper absorbers may be necessary to obtain adequate hot water compatibility.

Exhibit IV



A. SOLAR-EQUIPPED BUILDINGS (CUMULATIVE)

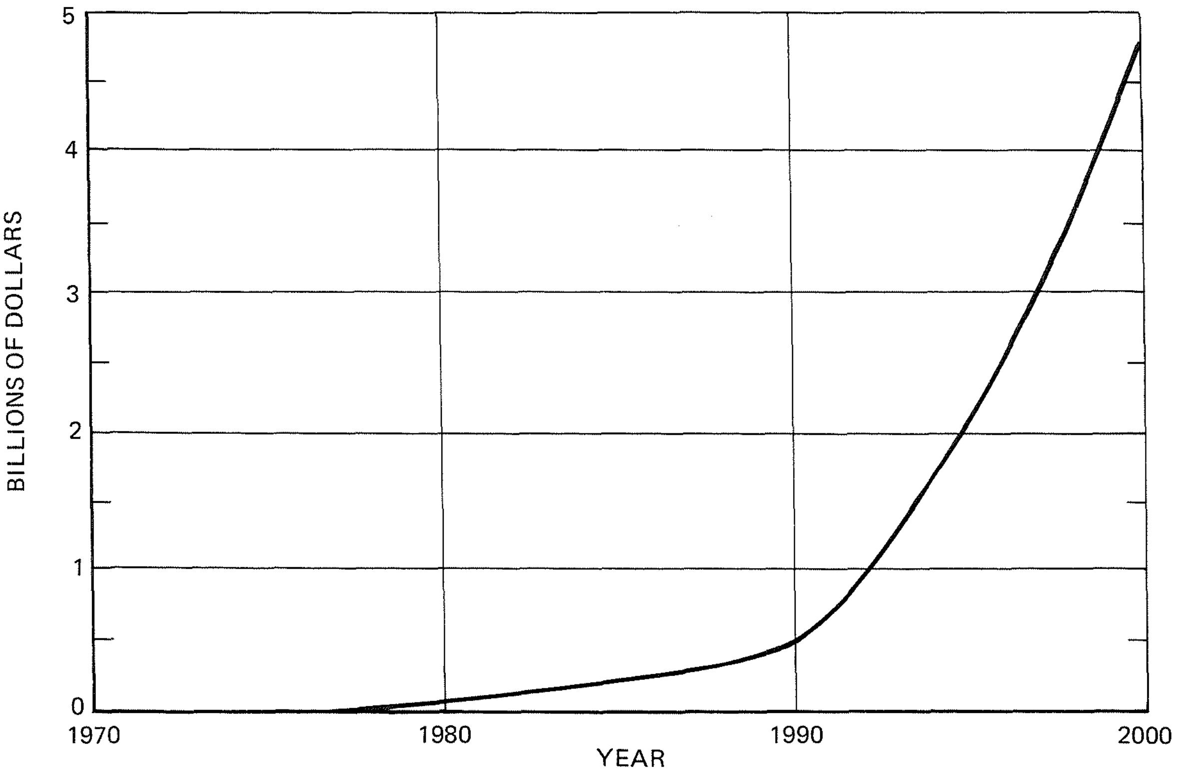


B. ANNUAL ENERGY SAVINGS

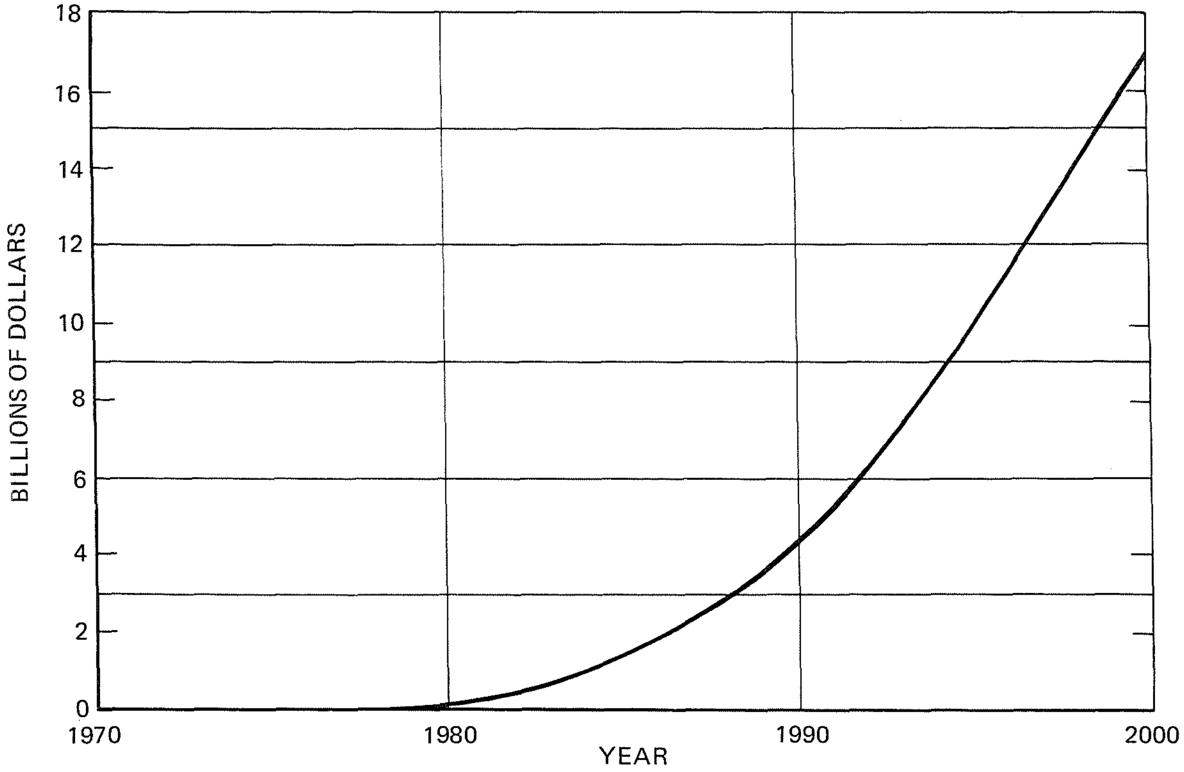
SOURCE: General Electric Corporation, Space Division, *Executive Summary: Solar Heating and Cooling of Buildings, Phase O Feasibility and Planning Study, Final Report,* Document Number 74SD4219, May 1974.

Figure 8. Market Penetration Projection Summary--New Construction Only.

Exhibit IV



C. ANNUAL FUEL VALUE SAVINGS (1970 $)



D. ANNUAL ADDED COST FOR SOLAR SYSTEMS

SOURCE: General Electric Corporation, Space Division, *Executive Summary: Solar Heating and Cooling of Buildings, Phase O Feasibility and Planning Study, Final Report,* Document Number 74SD4219, May 1974.

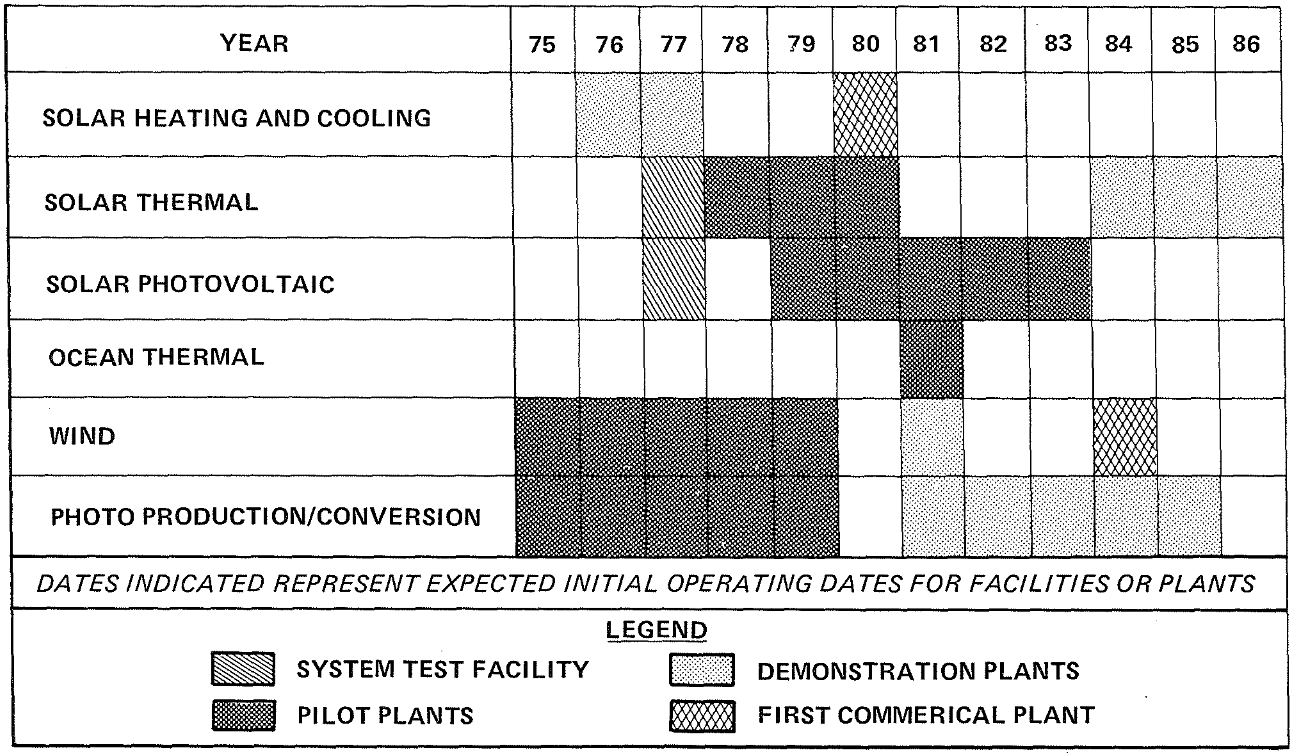
Figure 8 (Cont'd). Market Penetration Projection Summary--New Construction Only.

Exhibit IV

The costs of solar collectors are expected to drop significantly from their present price if mass produced. For production quantities of 100,000 to 1 million square feet per year (nominally 100-1,000 homes), one supplier expects a price to the home builder of \$3 to \$5 per square foot. Another supplier projects \$4.70 per square foot for single pane units and \$5.89 per square foot for double pane units at a production quantity of 32 million square feet per year. It is likely that the price of solar collectors will decrease even further as more suppliers become aware of the potential marketplace.

During the last year, prototype demonstration projects have been initiated, including partial solar space heating of four public schools (Baltimore, Maryland; Boston, Massachusetts; Minneapolis, Minnesota; and Warrenton, Virginia), development and testing of a solar transportable laboratory for heating and cooling experiments; and a solar heated and cooled home using absorption air conditioning at Colorado State University. In addition, recommendations have been made for extensive demonstration projects throughout the United States over the next 2-3 year period. These projects will span single family residences, multi-family residences, commercial/industrial buildings, and agricultural buildings.

It may be instructive to compare estimates prepared for the National Science Foundation by General Electric for the rate of penetration of this technology with two others: one made by the



YEAR	75	76	77	78	79	80	81	82	83	84	85	86
SOLAR HEATING AND COOLING		░	░			▩						
SOLAR THERMAL			▧	▓	▓	▓				░	░	░
SOLAR PHOTOVOLTAIC			▧		▓	▓	▓	▓	▓			
OCEAN THERMAL							▓					
WIND	▓	▓	▓	▓	▓		░			▩		
PHOTO PRODUCTION/CONVERSION	▓	▓	▓	▓	▓		░	░	░	░	░	

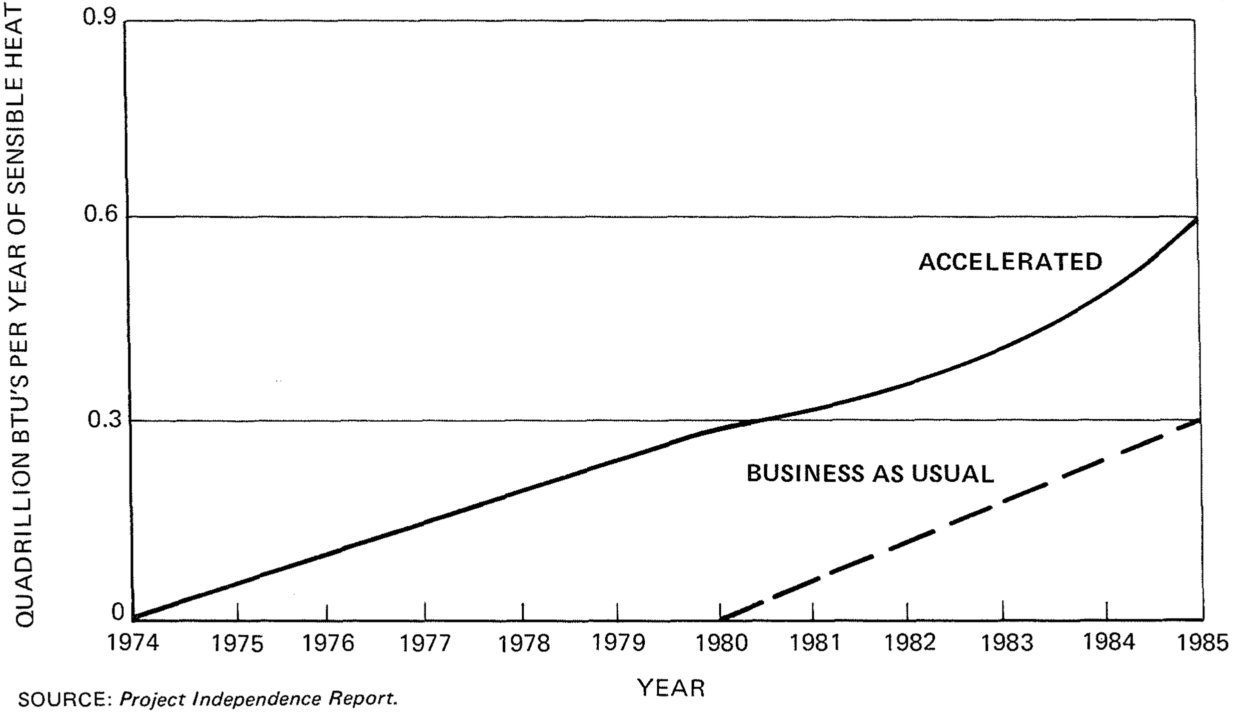
DATES INDICATED REPRESENT EXPECTED INITIAL OPERATING DATES FOR FACILITIES OR PLANTS

LEGEND

▧ SYSTEM TEST FACILITY
▓ PILOT PLANTS
░ DEMONSTRATION PLANTS
▩ FIRST COMMERICAL PLANT

Figure 9 . Federal Solar Energy Projected Implementation Perspective.

Exhibit IV



SOURCE: *Project Independence Report.*

Figure 10. Potential for Solar Heating and Cooling of Buildings.

Office of Science and Technology,* and another made by the FEA in the *Project Independence Report.*† (See Figure 9 for Federal Implementation Perspective.)

The Office of Science and Technology has estimated a 2.7 percent (approximately 5.4 quadrillion BTU's per year) reduction in the need for nuclear and fossil fuels in the year 2000 on the assumption that solar energy could provide an average of 80 percent of the heating and cooling requirements in 50 percent of new residential and commercial buildings (rising from a 10 percent installment rate in 1985). These savings represent a 10 percent penetration into the building space conditioning sector.

Figure 10 shows the FEA estimates of penetration for solar heating and cooling in two cases: (1) business as usual, and (2) an accelerated case. It can be seen that the business as usual case produces 0.3 quadrillion BTU's per year of sensible heating in the year 1985. These estimates were for the application of solar energy to supply the space heating and water heating requirements

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[*] Office of Science and Technology, *An Assessment of New Options in Energy Research and Development,* OST# AET-9, November, 1973, p. 112.

[†] FEA, *Project Independence Report,* Washington, D. C.: November, 1974, pp. 141-145.

of all new electrified residences and small commercial buildings. Therefore, using a heat rate of 10 thousand BTU's per kilowatt hour to provide the electrification, the fuel savings represented by this penetration are approximately 0.9 quadrillion BTU's per year (about 0.8 percent of national energy requirements in 1985). It should be noted, however, that not all solar energy applications will be in lieu of electric heating and cooling installations. A portion of the solar energy used is likely to replace fossil fuel heating where the savings would be proportionately less.

It is also useful to compare the above estimates with the results of a study conducted by General Electric for the National Science Foundation.* This study represents the most sophisticated analysis made to date of the market penetration expected for solar heating and cooling. The results are shown in Figure 8 and indicate about 300,000 solar-equipped buildings in existence in 1985 and an annual solar sensible heating capacity of 25 billion kilowatt hours, or 0.08 quadrillion BTU's. If these installations displace electrical resistance heating, the associated power plant fuel savings are 0.2 quadrillion BTU's, or less than one-quarter percent of national requirements in 1985.

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* General Electric Corporation, Space Division, *Executive Summary: Solar Heating and Cooling of Buildings, Phase 0 Feasibility and Planning Study, Final Report*, Document Number 74SD4219, May 1974.

Exhibit V

SOLAR THERMAL CONVERSION SYSTEMS

The solar thermal conversion alternatives being considered include: (1) central receiver systems and (2) distributed collector systems. Economic analyses performed by the Aerospace Corporation under contract to the National Science Foundation project busbar energy costs of approximately 30 mills (1974 dollars) per kilowatt hour (KWH) for a 199 megawatt (MW) central receiver solar thermal system, and 50 to 100 percent greater costs for 100 MW paraboloidal dish and parabolic trough systems for intermediate load applications (6 hours of storage). These cost estimates were made utilizing a simulated 1990 demand model for the Southern California Edison generation system and based on a solar model for Inyokern, California. Comparative performance for other cities throughout the Southwest indicate that costs would be 10 to 15 percent more for those locations compared to Inyokern assuming the same demand profile pertained.

Exhibit VI

HIGH VOLTAGE TRANSMISSION AS A COMPETITOR OF FUEL TRANSPORT

BASIS OF COMPARISON

The following comparisons are based on western coal with a heating value of 8.5 thousand BTU's per pound. The conversion from electric power or diesel fuel to BTU equivalent is on a direct basis (i.e., electric power at 3.413 thousand BTU's per kilowatt hour, [KWH] and diesel fuel at 140 thousand BTU's per gallon). In all cases, electric power's cost is $0.01 per KWH, which is equivalent to $2.93 per million BTU's.

Rail

The railroad figures are based on operation of 110 car unit trains consuming 1.4 gallons of diesel fuel per 1,000 gross ton miles and include fuel consumed during empty return of the trains. Railroad miles are taken to be about 30 percent greater than pipeline or extra-high voltage (EHV) transmission distance on the basis that the existing rail network will be used, whereas a new direct pipeline or EHV system would be built. This mileage factor has been developed from several specific cases. However, it can vary, depending on specific applications. In addition to diesel fuel consumption, a BTU loss of 1 percent due to windage has been included in the rail case.

EHV Transmission

Losses in transmission at EHV were derived from the 1970 *National Power Survey* of the Federal Power Commission, where losses for line sizes of 345 kilovolts (KV), 500 KV, and 765 KV were given. Table 32 summarizes the data used.

TABLE 32

LOSSES IN EXTRA-HIGH VOLTAGE TRANSMISSION--1970

Load (MW)	Coal Equivalent (MMTA)	Loss (MW per 100 Miles)	Loss per 100 Miles (Percent)	Loss (Billion BTU's per 100 Miles per Year)
900	2.7	30	3.3	896
2,000	6.0	38	1.9	1,135
4,000	12.0	68	1.7	2,030

Source: Federal Power Commission, *National Power Survey*, 1970.

Exhibit VI

The conversion of line loading in megawatts (MW) to the equivalent coal tonnage required to generate that power was based on western coal, where 3 million tons per year of coal would be required to fire a 1,000 MW plant.

Slurry Pipeline

Energy requirements for pipeline transportation of coal were derived from a recent detailed study of a pipeline system for transportation of 25 million tons per year of coal for a distance of 1,000 miles across the central United States. Energy requirements for slurry preparation, agitated storage tanks, pipeline pumps, and dewatering are included. All other energy requirements associated with this system are included except for that consumed by motor vehicles and airplanes used in pipeline operation and maintenance.

The energy consumed by the 1,000 mile, 25 million tons per year, base pipeline system is 2.6 percent of the energy transported. Sources of this energy are: electric power, 23 percent; low pressure extraction steam, 15 percent; and coal, 62 percent.

Electric power is used in the slurry preparation process to grind the coal to a size suitable for slurry pipeline transportation. Other major uses of electric power in the slurry preparation process are for transfer pumps and slurry storage tank agitators. The power used for crushing and grinding (about 75 percent of the total for preparation) is a savings to the coal customer (i.e., the power plant) since the coal is crushed to an even finer size for the pulverized coal boiler. Therefore, credit has been considered in the calculation of savings to the power plant. The net power required for slurry preparation is about 2.5 percent of the power requirement used for the base case. Energy consumption in slurry preparation is proportional to the tons prepared.

Electric power is also used to drive the main pipeline pumps and their auxiliary equipment. This power requirement represents about 17.5 percent of the BTU's consumed in the base case. Pumping power varies approximately with the square root of throughput and is proportional to pipeline length.

The main energy requirement for the dewatering terminal of the pipeline system is coal burned in the thermal driers which is 77.5 percent of the energy requirement in the dewatering terminal. The cost of this coal is made up of the F.O.B. mine price of the coal plus the incremental cost of transportation of about 1-1/2 percent additional coal in the pipeline system. Low pressure extraction steam is also used in the dewatering process which is obtained from the power plant to which the coal is being delivered. This is basically waste heat which is figured into the coal comparison at $0.25 per million BTU's. Extraction steam represents about 20 percent of the energy requirement at the dewatering terminal. The remaining 3 percent of the energy requirement is provided by electric power. Dewatering energy requirements are proportional to system throughput.

Exhibit VI

Barge

Obviously, efficient barge transportation depends on the availability of suitable waterways which will allow multi-barge units to be transported. A basic energy requirement of 540 BTU's per ton mile is considered normal for this form of transport. The waterway distance will, in every case, be longer than the direct distance from terminal to terminal. However, the figures shown here are not adjusted for this fact. Any comparison of specific cases using barge transport or multi-mode transport must consider the differences in transport distance inherent in the alternative modes of transportation.

Exhibit VII

VERY LONG-TERM DEVELOPMENTS IN POWER TRANSMISSION AND POTENTIAL FOR ENERGY CONSERVATION

CRYOGENIC CABLES

Technology in cryogenic cable systems has not advanced to a sufficient degree to be considered for potential loss reductions within the 1979-1985 period. Superconducting transmission technology can be expected to be introduced between 1985 and 1990. A full-scale, working prototype is expected to be ready by 1979, and a fully commercial cable capable of competing economically at the 3,000 megavolt-ampere (MVA) level is expected to be available by 1984/1985.

An increasing trend toward underground transmission is expected. The search for increased underground line power densities (e.g., forced oil cooled cables) will result in power loss rates three times the loss rates found in conventional underground cables. The use of cryogenic cables could reduce these loss rates by 40 percent in the case of resistive cryogenics (approximately 70° Kelvin [K]) and 94 percent in the case of superconducting cryogenics (approximately 4°K), both relative to forced oil cooling.

Looking at high capacity (more than 2 giga-volt-ampere [GVA]) cables in the year 2000, under the assumptions of a quadrupling of electrical generating capacity and a 5,000 GVA-mile market for superconducting cables, one can estimate an annual reduction of line losses of 0.4 quadrillion BTU's (equivalent to 200 thousand barrels of oil per day), relative to losses which would be experienced if forced oil cooled cables were used. The savings for cable capacities under 2 GVA have not been estimated here. For these capacity levels, compressed gas insulated cables (with loss rates only 1-1/2 to 2 times those in superconducting cables) may find application.

The factors which make it difficult, at this time, to estimate the rate of introduction of cryogenics are: the relative amounts of distributed *versus* central generating capacity; the rate and degree to which undergrounding of transmission cables will take place; the number of circuit-miles of high capacity cables which will be required; and the reliability and economics of these systems.

HYDROGEN AS A MEDIUM FOR TRANSPORTING "ELECTRICITY" BETWEEN POWER PLANT AND CUSTOMER'S FUEL CELL

As hydrogen produced by electric power would be more costly than the power itself, there must be offsetting economies of transmission and distribution of hydrogen for it to be economically competitive.

Exhibit VII

The advantage of pipelining fuel derives from the economies of scale as the system size is increased to very large capacities, lowering the unit-energy transfer cost. Electric power systems achieve the same effect by going to higher transmission voltage levels. It is estimated that a standard 36 inch gas line could carry hydrogen equivalent to 21 trillion BTU's per hour, or 6,154 MW. This is about six times the capacity of a long 500-KV line without compensation. Another advantage of hydrogen gas transmission would be that significant quantities may be stored in the pipeline by varying operating pressure.

It is not certain that existing natural gas mains could safely handle hydrogen because of its high leakage coefficient. Unless adequate sealing techniques are developed, a new distribution system might be required.

Exhibit VIII

FUEL SUBSTITUTION POSSIBILITIES PERTINENT TO THE 1980'S

The electric utility industry is an important area to promote the energy conservation effort to conserve scarce fuel resources. Two reasons exist: (1) the industry itself is a significant user of scarce fuels and insofar as it can improve its efficiency by conversion or shifting its generating requirements to more plentiful fuels, demands on scarce supplies will be reduced; and (2) electricity generated from plentiful resources can be substituted for scarce fuels in end-use markets, saving not only at the point of ultimate consumption, but also in processing and transportation markets. Only the first of these reasons falls within the scope of this report. The following is an analysis which quantifies the electric power industry's potential for minimizing its own use of oil and gas through 1985, under varying assumptions of growth in electric energy demands.

For this analysis, several utility views were solicited regarding the possible ranges of energy demands and fuel mixes for the 1980-1985 period. Based on these estimates, representative minimum and maximum growth scenarios were established along with fuel mixes which conformed with reasonable constraints on fuel availability while holding gas and oil use to a realistic minimum. Both scenarios appear on Table 33.

The low growth case assumes a steady increase in the demand for electricity between 1974 and 1985 at the rate of 4.5 percent per year. To supply this energy, it projects a "low" installed mid-year nuclear capacity of 80 gigawatts (GW) in 1980 and 150 GW in 1985, operating at capacity factors of 60 percent, or 5,260 hours per year, and 70 percent, or 6,130 hours per year, respectively. Gas available for power generation is assumed to decline at an increasing rate so that by 1985, gas-fired generation represents only 35 percent of its 1974 value. Oil use conforms with the President's October 8, 1974 proposal of reducing power plant consumption by 1 million barrels per day by 1980. Hydropower is predicted to grow by only 15 percent through 1985 and small amounts of generation from geothermal sources and the combustion of municipal waste are assumed. The remaining fuel requirements are supplied by coal; its consumption by the utility industry increases by 70 percent between 1974 and 1985 with the greatest increase coming between 1974 and 1980. During this 6 year period, coal use by utilities would rise from near 400 million tons to some 630 million tons.*

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* The 1980 coal requirement would represent about 70 percent of the coal industry's potential output under "business as usual" conditions as estimated by the FEA in its *Project Independence Report*.

Exhibit VIII

TABLE 33

REPRESENTATIVE UPPER AND LOWER GROWTH TRENDS OF ELECTRIC POWER POWER GENERATION AND THEIR IMPACTS ON FOSSIL FUEL REQUIREMENTS--1974-1985

	1974		1980		1985	
Low Case*	Billion KWH	Trillion BTU's	Billion KWH	Trillion BTU's	Billion KWH	Trillion BTU's
Nuclear	115	1,210	420	4,410	920	9,660
Coal	855	8,635	1,360	13,870	1,480	14,800
Oil	290	3,130	100	1,100	100	1,050
Gas	310	3,410	220	2,420	110	1,210
Subtotal	1,570	16,385	2,100	21,800	2,610	26,720
Hydroelectric	277	2,910	300	3,150	320	3,360
Geothermal	3	30	7	74	20	210
Wood and Waste	-	-	3	31	20	200
Total	1,850	19,325	2,410	25,055	2,970	30,490
High Case†						
Nuclear	115	1,210	512	5,380	1,640	17,220
Coal	855	8,635	1,456	14,930	1,875	18,280
Oil	290	3,130	400	4,300	100	1,050
Gas	310	3,410	220	2,420	110	1,210
Subtotal	1,570	16,385	2,588	27,030	3,725	37,760
Hydroelectric	277	2,910	300	3,150	320	3,360
Geothermal	3	30	7	74	40	420
Wood and Waste	-	-	5	51	40	400
Total	1,850	19,325	2,900	30,305	4,125	41,940

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* Annual growth rate of kilowatt hour consumption for the 1974-1985 period is projected to be 4.5 percent per year.

† Annual growth rate of kilowatt hour consumption is projected to be 7.8 percent per year for the 1974-1980 period and 7.3 percent per year for the 1980-1985 period.

Exhibit VIII

This low growth scenario would permit the reduction of combined oil and gas consumption by 65 percent between 1974 and 1985, in conjunction with achievable increases in coal and nuclear output. However, the assumed low rate of electricity growth is considered improbable. More probably, higher growth rates imply diminished chances of achieving the proposed reduction in oil consumption, especially in light of seemingly inevitable cutbacks in gas availability.

The high growth scenario for electricity consumption projects a continuation of historical growth rates through 1985, with annual growth increments of 7.8 percent per year until 1980 and 7.3 percent per year from 1980 to 1985. Such vigorous growth probably implies a considerable substitution of electricity for oil and gas in end-use markets; as mentioned earlier, no effort has been made here to quantify the additional effects of such substitution.

In this scenario, hydroelectric production is the same as in the low growth case. Generation from geothermal sources and refuse in 1985 is twice that assumed in the low growth case but it is still of little consequence.* Gas availability is reduced at the same rate as in the low growth case but nuclear production is assumed to be 22 percent higher by 1980 and 78 percent higher by 1985. The nuclear figures are based on expected mid-year installed capacities of 90 GW in 1980 and 250 GW in 1985, operating at respective capacity factors of 65 percent, or 5,690 hours per year, and 75 percent, or 6,570 hours per year.† Coal use would more than double in this scenario rising from nearly 400 million tons in 1974 to around 825 million in 1985, with a 1980 consumption of over 675 million tons. Meeting such a coal demand would tax the mining industry's expansion capability, especially if growth in coal consumption by other sectors of the economy is also assumed.

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* The EPA has projected an annual energy potential from refuse of something less than .7 quadrillion BTU's per year in 1985. It has been assumed for the high case that at most, 60 percent of this total could be converted to electric energy at a heat rate of 10 thousand BTU's per KWH, equivalent to 40 billion KWH.

Geothermal generation for 1985 was estimated on the basis of some 7,000 MW in operation (high case) with an annual utilization of 6,000 hours.

† As of October 1, 1974, the Edison Electric Institute (EEI) *Semi-Annual Electric Power Survey* showed some 183,000 MW of nuclear capacity in operation or scheduled for commercial service. Over 100,000 MW of this total was for 1980 or later operation. With present lead times on nuclear plants approaching 10 years, the installation of 250,000 MW of nuclear by 1985 would appear to be the maximum achievable unless changes in licensing procedures were to dramatically reduce lead times.

Exhibit VIII

In this scenario, oil consumption by the electric utility industry could not be reduced by 1980 as outlined in the President's proposal. In fact, oil requirements for power production in 1980 would increase by 37 percent over 1974, rising from some 1.4 million barrels per day to nearly 2 million barrels per day.* This increase results from near-term limitations on the expansion of nuclear and coal fired generation which restrict the combined increase in energy from these two sources to hardly more than 100 percent between 1974 and 1980.

After 1980, the scenario reflects considerable improvement in the utility industry's potential for reducing both oil and gas consumption in spite of continued rapid growth in electricity requirements. Thus, a net decline in oil use of 1 million barrels per day compared to 1974's consumption could prove possible. It must be stressed, however, that attaining such a goal while supplying rapidly rising energy demands would entail strenuous efforts in the coal and nuclear industries. In the case of nuclear plants, capacity would have to be added at an average rate of 32,000 MW per year between 1980 and 1985. Such development would require solution of the financial and licensing problems which now hinder the development of nuclear plants for the 1980's.

The two representative scenarios defined here only describe possible cases toward the upper and lower limits and, of course, there exists an infinite number of potential growth trends and fuel mixes which lie between these extremes. One can envision development which involves a somewhat slower growth in nuclear and/or coal output, and a net reduction of oil and gas use identical to that outlined above. Conversely, one can imagine a slightly lower growth in electricity requirements associated with much higher oil consumption, if both coal and nuclear developments are sufficiently constrained. In any case, it appears that a dramatic reduction in oil use projected for electric utilities is not likely by 1980 but may be feasible by the mid- to late 1980's. Only under the assumption of a very low growth rate in overall electricity requirements could such an objective be achieved by the end of the present decade.

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* It should be noted that even an oil use rate of 2 million barrels per day would be low compared to many estimates made previously. For example, the October 1, 1974, EEI *Semi-Annual Electric Power Survey* contains a fuel requirements projection which indicates a 1979 utility oil need of 838 million barrels, equivalent to an average daily consumption rate of 2.3 million barrels.