Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

ENERGY ANALYSIS PROGRAM

Chapter from the Energy and Environment Division Annual Report 1980

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Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

ENERGY ANALYSIS PROGRAM

FY 1980

Lawrence Berkeley Laboratory
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Berkeley, California 94720

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ENERGY ANALYSIS PERSONNEL

FY 1980

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INTRODUCTION

R. Ritschard

The Energy Analysis Program is concerned with energy impacts of many different kinds; these include impacts on regional and local economies and ecologies; on water availability and quality; on air quality; on land use; and on human health. These issues are studied from two perspectives.

The first perspective embraces the impacts of a specific technology, such as coal combustion, enhanced oil recovery, geothermal power, or solar energy and the economic, environmental, and institutional constraints on their use. Alternatively, this type of study focuses on a particular energy end use sector, e.g., agricultural, commercial, residential, or industrial, and addresses the impacts of, and constraints on, the use of alternative energy supplies to satisfy the demands of this sector.

The second perspective includes integrated assessments of regional and subregional impacts of alternative future energy supply systems and energy demand growth patterns. For these regional assessments, our energy analysts examine each major impact type for Federal Region IX (Arizona, California, Hawaii and Nevada), or for individual states, such as Hawaii.

The major integrated subprograms arise from national energy policy (contemplated or enacted) and from major energy research and development programs. In conjunction with the other national laboratories, LBL has participated in assessing national energy plans, energy supply technologies, and building energy performance standards. For the past several years, the Energy Analysis Program staff has taken a leadership role in analyzing the direct and secondary impacts on each economic sector as a result of the capital investment, direct employment, and material demands of each technology. During the past fiscal year, LBL accepted lead responsibility for conducting assessments of energy-related activities in the Pacific Coastal Zone (this includes the coastal areas of Alaska, California, Hawaii, Oregon, and Washington).

During FY 1980, a number of studies were conducted that are covered in the short reports that follow. The reports are grouped in three general categories although the analyses in many cases overlap each other.

Several energy technologies were described and assessed, including biomass energy systems in Hawaii; marine kelp conversion along the California coast; enhanced oil recovery; geopressured geothermal resource in the Gulf Coast region; acid mine drainage from increased use of coal; and other solar technologies. The assessments were on such topics as the direct and secondary economic impacts at the national and regional level; groundwater impacts; institutional constraints; and various environmental impacts.

The regional studies were made at several geographic levels including Federal Region IX, the Pacific Coastal Zone, and the State of Hawaii. The primary effort was to analyze the major environmental, socioeconomic, and institutional issues resulting from the Second National Energy Plan (NEP-2), from renewable energy resource development in Hawaii, and from energy-related activities in the coastal zone of the West Coast (of the U.S.).

A series of energy efficiency studies also have been undertaken. These studies evaluated energy performance standards for residential buildings; energy standards at the local and state levels; energy efficiency standards for appliances; and residential energy demand forecasting. In addition, two studies are included that address energy demand and conservation from an international perspective. The findings of all these assessments are intended primarily to aid decision-makers in formulating energy policy and energy research and development programs.

BIOMASS ENERGY CONVERSION IN HAWAII*†

R. Ritschard and A. Ghirardi

INTRODUCTION

Biomass is Hawaii's most productive natural energy resource in terms of the electricity generated from it. Further, it is the only indigenous resource that can be converted to liquid fuels to replace imported petroleum fuels. Direct combustion of bagasse (a fibrous sugar cane residue), wood chips, and macademia nut shells generates approximately 12% of the electricity now consumed in the state. Several studies have outlined a program of biomass energy use in Hawaii and have concluded that biomass can supply more than 15% of Hawaii's energy needs in the next two decades.

Fuels can be derived from several biomass resources: wastes, which include all organic materials that accumulate at specific locations and whose disposal carries an associated cost, e.g., municipal solid wastes (MSW), lumber mill wastes, and sewage sludge; residues, which are plant materials left in the field or forest after agricultural crops or timber are harvested; and energy crops, i.e., those crops specifically cultivated for their fuel content. Some recently proposed energy crops for Hawaii are aquatic plants (to be cultivated in land-based systems), ocean kelp, corn, sugar cane, and various tree crops, such as eucalyptus and giant koa haole.

Technologies that convert biomass to energy and that are believed to have the greatest potential in Hawaii for the near-term (before the year 2000) include direct combustion of wastes--such as bagasse, MSW, and pineapple trash--and the production of liquid fuels, especially ethanol from various feedstocks, e.g., cane juice, molasses, and pineapple. Biomass is the only renewable resource that will be suitable for conversion to liquid fuels before the turn of the century.

The most important factor in the use of biomass for energy is its availability as a resource. For Hawaii, four major biomass resources appear most available. These include (1) Hawaiian sugar industry resources (bagasse, cane juice, leafy trash, and molasses), (2) tree crops, (3) municipal solid wastes, and (4) algae. Of these, only the sugar industry products and trees are now available in sufficient quantities to supply a significant amount of Hawaii's future energy needs.

MAJOR FINDINGS

The biomass resources in Hawaii with the greatest potential to displace imported petroleum are outlined in this study. Emphasis is placed on conversion technologies that will meet the economic and technical constraints for the near-term (before the year 2000). Conversion technologies selected include direct combustion of wood chips and wastes (such as bagasse, MSW, and pineapple trash) and the production of liquid fuels, especially ethanol, from molasses.

Energy from aquatic biomass, i.e., kelp and other algae, will not be a viable energy source in Hawaii during the time period of this study. This is because system costs would be high and because advancements are required in feedstock cultivation, harvesting, and processing.

Direct combustion of municipal refuse, primarily on the island of Oahu, could supply up to 5% of the state's electricity demand in the year 2000. This electrical supply would consist of approximately 70 MW per year in the City and County of Honolulu and 10 MW on the other islands combined.

Bagasse, which is already a significant contributor to the electrical supply of Hawaii, will be an important source of biomass in the future. Currently, about 25 MW of electrical power are sold to the utility grid annually by the sugar industry, after supplying its own needs. With adequate financial incentives, sugar companies could expand this capacity by the 1990's so that they could sell up to 50 MW annually. However, various changes would need to be implemented in sugar plantations' growing, harvesting, and processing practices, including the drying and pelletizing of bagasse for more efficient storage and combustion.

Another sugar industry by-product, leafy cane trash, has some potential as a biomass feedstock. However, for cane trash to be available in quantities adequate to support a major conversion process, new harvesting techniques must be developed and used. If that proves feasible, an additional 11 trillion Btu's of energy would be available. The authors believe that the sugar mills will burn the cane trash rather than use it as a feedstock for the production of ethanol. Since the conversion of cellulosic products, such as cane trash, first requires either acid or enzymatic hydrolysis before fermentation to ethanol, it seems likely that combustion of this material is a more cost-effective use.

Tree crops are one of the more promising biomass resources available in Hawaii during the next two decades. Currently, some use is made of wood chips by direct combustion in sugar mill boilers.

* This work was supported by the Resource Applications Division, U.S. Department of Energy, under Contract No. W-7405-ENG-48.

† Condensed from R. Ritschard and A. Ghirardi, Biomass Energy Conversion in Hawaii, Lawrence Berkeley Laboratory report LBL-11902, 1980.

A successful wood biomass program will require that large acreage be planted in tree crops, such as eucalyptus and giant koa haole. Capital costs for an extensive tree farm in Hawaii have been estimated at $2500/acre. Although the conversion of wood to methanol and gasoline is an attractive alternative, the authors feel that the most cost-effective method of conversion is by the direct combustion of wood chips to produce electricity. The range of electrical capacity available in the year 2000 is estimated in this analysis to be between 150 MW (100,000 planted acres) to 480 MW (300,000 planted acres). The more probable level is about 320 MW, if 200,000 acres of eucalyptus and other tree crops are planted and harvested. The major uncertainty for any wood conversion process is the cost of conventional energy sources and the competing economic uses for wood, such as for lumber or paper pulp.

Other feedstocks, such as macadamia nut shells, pineapple trash, and hay, are available for direct combustion. The macadamia shells will probably continue to be used to a limited extent by the macadamia nut industry, but will not make an overall contribution to the state's energy needs. Combustion of pineapple trash, however, could contribute as much as 5 MW by the year 2000, especially for the County of Maui (Maui, Molokai, and Lanai). Hay is also available on the island of Molokai as a replacement for diesel fuel. This biomass resource could contribute about 2 MW of electricity annually by the late 1990's.

Finally, at today's prices, ethanol is not competitive with gasoline. The use of ethanol-gasoline blends has required government subsidies as well as by-product credits and will continue to do so in the near future. In Hawaii, molasses is the only feedstock likely to be available for production of alcohol over the next decade or so, barring a collapse of the international sugar market. If all molasses were used for production of ethanol, gasohol could displace 7-10% of the State's gasoline consumption (at 1978 levels), or some 20-30 million gallons per year. (See Fig. 1). As for leafy trash, wood, and other cellulosic materials, their use as boiler fuel will be their best contribution to displace imported liquid fuels in the state.

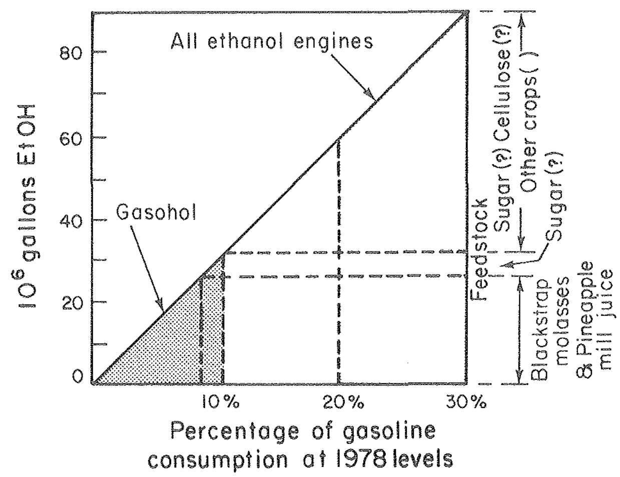

Fig. 1. Strategy for use of gasohol. (XBL 114-2334)

Several things stand in the way of fully utilizing biomass as an energy source for Hawaii. Some agricultural wastes and sugar industry products and by-products are currently more valuable as human and animal food than as energy sources. Molasses, for example, is now used to manufacture beverage ethanol, industrial alcohol, and animal feed and sells for between $70 and $100 a ton. At today's prices, the ethanol that would be made from molasses is not competitive with gasoline. Gasohol use to date has been supported by government subsidies, which are expected to continue. Gasoline would have to cost about $1.70 a gallon to make gasohol attractive or even competitive. In addition, tree crops, which are one of the most promising biomass resources available in Hawaii within the next 25 years, require substantial land areas. It would take a political decision to support the energy market for biomass or a drastic shift in existing market values to redirect existing biomass resources entirely into an energy-producing program. The technical problems that currently confront such a program are no greater than the economic and political barriers.

PLANNED ACTIVITIES IN FY 1981

This project was completed in FY 1980 and will not continue in FY 1981.

MARINE KELP: ENERGY RESOURCE IN THE COASTAL ZONE*†

R. Ritschard and K. Haven

INTRODUCTION

The assessment of energy-related impacts in the coastal zone has focused primarily on thermal power plants and outer continental shelf (OCS) petroleum development. However, there is a growing list of energy resources and conversion systems within the coastal environment that are currently being proposed. Marine biomass is one of the most recent entries on this list of coastal energy resources.

A marine biomass farm is one of the few biologically-based systems that has the potential to contribute large quantities of synthetic gaseous fuels to the nation's energy supply. This is especially true in that large surface areas are available on the ocean and large amounts of plant nutrients are available in the ocean waters. The California giant kelp (Macrocystis pyrifera), which is well established as a valuable coastal resource and a source of chemical products (algin), is a prime candidate for energy conversion, since it is efficient in converting sunlight into a fixed source of energy. In turn, kelp can be processed by anaerobic digestion or other procedures into methane. Furthermore, other by-products such as food, fertilizer, ethanol, and industrial material can be obtained.

This paper describes an ocean farm system that has been designed and used as an ocean test facility by the Energy from Marine Biomass Program, jointly sponsored by the Gas Research Institute and the Department of Energy and managed by the General Electric Company.[1] Figure 1 shows a generalized diagram of the marine biomass system used in this analysis.

The analysis of the ocean farm system includes a description of the types of impacts that might occur if large-scale operations begin, such as the production of environmental residuals, conflicts with the fishing and shipping industries, and other legal/institutional impacts. Finally, the relationship of the marine biomass concept and coastal zone management plans is discussed.

MAJOR FINDINGS

Environmental Impacts

The coastal regions of the United States are relatively rare, biologically important, and vulnerable to human perturbation. The coastal zone has been and will probably continue to be important in the industrial development of the nation. The placement of energy facilities along the coast,

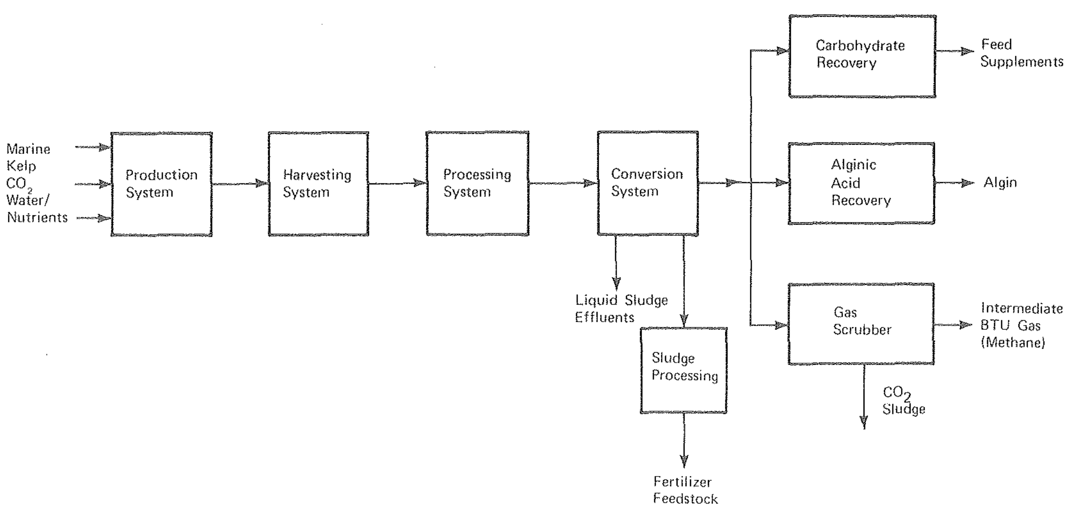

Fig. 1. Complete marine biomass system. (XBL 781-13495)

* This work was supported by the Regional Impacts Division, Office of Environment, U.S. Department of Energy, under contract No. W-7405-ENG-48.

† Condensed from R. Ritschard and K. Haven, "Marine Kelp: Energy Resource In the Coastal Zone." Coastal Zone 80, vol. 2, November 1980, pp. 967-979.

however, generates environmental impacts and creates conflicts in the use of our coastal resources.

Marine biomass has been suggested as an energy resource, since it has the potential to contribute significant quantities of gaseous fuels to the nation's energy supply. As part of another project, an ocean farm system, using the California kelp (Macrocystis pyrifera) has been designed and used as a test facility off the southern California shore.

Every energy conversion system has various impacts. Since there are no full-scale systems in operation, the data represent a compilation of potential impacts from bench-scale experiments, test farms, and from the conceptual plans for production, harvesting, and processing. The impacts of a massive open-ocean farm operation have not been explored. There is a potential for significant climatic modifications. The anticipated climatic changes stem from the massive artificial upwelling that will be required to stimulate kelp growth and maintain it at high rates. When large volumes of cold deep water, which are rich in nutrients and supersaturated with carbon dioxide, are brought to the ocean surface to fertilize the plants, events might occur that could lead to regional and global changes in climate. The culture and harvesting of seaweed over several thousand square miles of ocean surface could result in changes in albedo, air-sea exchanges of materials, and altered ocean surface roughness. The farm structures themselves will reduce or change the patterns of water circulation. These factors, which could change prevailing weather patterns and create additional fog banks, subsequently may have some effect on the productivity of the kelp beds.

A potential problem associated with the farm structure itself is the release of numerous chemicals into the ocean from the supports and synthetic lines used to hold the algae. Hruby (1978) noted the possibility of a slow release of toxic metals from the antifouling paints and organic chemicals used on the farm structures.[2] The seriousness of this chemical pollution problem is as yet unknown.

The upwelling system, which is designed to provide an abundance of nutrient rich water needed for kelp growth and development, could present several environmental problems. Included in this category are changes in the rate of productivity; alteration of salinity, temperature, dissolved oxygen, turbidity and nutrient levels; possible entrainment of marine organisms that cannot resist the vertical inflow velocities; and the potential air emissions related to the use of diesel-powered pumps.

Harvesting of the marine biomass system will be done with ships of Kelco Company design. These ships will create some environmental impact due to their emissions during normal operation. The Kelco ships burn diesel as a fuel, resulting in the production of particulates, nitrogen oxides, and hydrocarbons as primary air pollutants. These pollutants, however, will be diffused over a larger area than the kelp farm itself, since they are released as the ships travel to and from the farm.

The waste water generated from the shredder, presser, and digester during the processing phase will eventually be discharged into the sewer system. The composition of this effluent and the degree of pollution control that is necessary are unknown at this time. It is assumed, however, that the processing plant will conform to Environmental Protection Agency discharge permit standards regarding waste water effluents.

As a final step in the marine biomass system, the processed algae is fed into the anaerobic digester. The gas mixture from the digester must be passed through a scrubber to separate carbon dioxide, which is about 40 percent of the gas, from methane. The major environmental residual resulting from this stage of the process is sludge from the scrubber that must be collected for subsequent disposal. The composition of the sludge from the scrubber, as well as from other phases of processing/conversion, is also unknown. However, since marine algae will concentrate various heavy metals, the sludge may possibly contain considerable levels of heavy metals. If any of this sludge is to be used for fertilizer feedstock, it will require some detoxification.

The final concentration of heavy metals and other toxicants, and the biological oxygen demand and organic loading of the aqueous discharge, cannot be anticipated without specific measurements from a test, demonstration, or prototype facility. Until that information is available, only the potential environmental impacts can be identified.

Legal and Institutional Impacts

Algal farms, depending on their size and location, may have a negative impact on commercial shipping lanes. At a projected biomass yield of 50 dry-ash-free tons/acre-year, it has been estimated that about 55,000 $mi.^2$ of ocean surface might be needed to supply the nation's current requirements for natural gas.[1] This area (approximately 235 mi. by 235 mi.), if concentrated offshore of the California coastline, might provide an additional hazard to ocean commerce.

In addition, such large marine biomass farms may adversely affect access to, and utilization of, coastal fishing locations. The potential exists for impacts on recreational and commercial fishing in the farm area. Since the kelp farms themselves will probably attract certain fish species, the further legal issue of trespassing on the marine farm and other liability questions arises.

Several institutional and legal issues are likely to accompany the research, development, and commercial phases of the open ocean system if they are located beyond the 12 mi. (territorial seas) or 200 mi. (high seas) limit. The current biological test farm is deployed about 4.5 mi. offshore from Laguna Beach in southern California. The prototype and commercial farms may be located as far as 20 mi. offshore. Not only will the international and domestic legal status have to be analyzed, but a regulatory framework will have to be established to guarantee the various uses of marine resources.

Legal questions include, but are not limited to, liability for: collisions between ships and the substrate or associated fixed structures; blockage of fishing rights and lanes; interference with shipping and navigation; residuals released from the farm structure; and the cold water plume's impact on coastal areas or fishing grounds.

Finally consideration is given to how the introduction of a new energy technology, such as marine biomass conversion, interacts with the coastal zone planning process. Major concerns with the offshore aspects of the ocean farm concept exist, including the overall lead regulatory authority; the question of federal consistency; and impact planning and mitigation by local coastal governments. Onshore activities will probably pose fewer problems, since the proposed facilities are not unlike those already sited in the coastal zone.

The conclusion is that the proponents of a biomass energy system should start early to promote a timely transfer of information between the various institutions (federal, state, and local) involved in coastal zone planning. The accurate prediction of environmental impacts and their mitigation, required by law, demands a fully-coordinated energy planning and coastal resource management process.

PLANNED ACTIVITIES IN FY 1981

This work was concluded in FY 1980 and will not continue in FY 1981.

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2. T. Hruby, "Environmental Impacts of Large Scale Aquatic Biomass Systems," in E. Ashare et al., Cost Analysis of Aquatic Biomass Systems (Cambridge, Mass., Dynatech R&D Company, 1978.)

ECONOMIC IMPACTS OF ENERGY FUTURES*

J. Sathaye, H. Ruderman, and P. Chan

INTRODUCTION

The Energy Analysis Program is the "lead laboratory" for national socioeconomic analysis under several programs sponsored by the Department of Energy's (DOE) Office of Environmental Assessment. In this role, we analyse the regional and national direct and indirect economic impacts, associated with energy scenarios formulated by DOE. Direct economic impacts include the capital, material, and equipment needed to construct, maintain, and operate the energy facilities required by the scenario. Indirect impacts include the secondary industrial output, income, and employment generated by the capital and manpower expenditures for new construction. During the past few years, we have developed a set of interconnected models to evaluate national and regional economic impacts. These were used in assessing the effects of accelerated coal utilization and an assessment of the President's first National Energy Plan (NEP). This work has been described in previous Annual Review articles.

ACCOMPLISHMENTS DURING FY 1980

During FY 1980, we continued to improve our analytic methodology for evaluating economic impacts and to apply this methodology in assessing specific scenarios. We have incorporated twenty additional solar technologies in the Energy Supply Planning Model. Our National Input-Output Model has been modified to take into account 1972-1977 price changes. The method for regionalizing indirect impacts has been completely revised. We analysed a total of four scenarios during the year--two for the Technology Assessment of Solar Energy (TASE) program and two for the Regional Issues Identification and Assessment (RIIA) program. In this report we will describe the change we made to the models, and we will discuss some of our analytical results for the four scenarios.

Methodology Improvements

The interlinkage of the models we use for calculating direct and indirect economic impacts is shown in Figure 1. The Energy Supply Planning Model (ESPM) is an adaptation of the original model formulated by the Bechtel Corporation.[1] It translates a scenario into a schedule of the number of facilities which have to be constructed and operated to meet the projected levels of energy supply. The capital costs and the annual manpower, equipment, and materials needed to construct, maintain, and operate the facilities are calculated. The original ESPM data base had information mainly on requirements for conventional technologies. We modified the data base to include data on twenty solar and other renewable technologies. The detailed requirements at the four-digit Standard Industrial Classification (SIC) level were determined at LBL and other national laboratories as part of the TASE program.

The input-output model of the U.S. economy is used to calculate secondary output, income, and employment. The I-O model was originally based on the 1967 national table constructed by the

* This work was supported by the Office of Environmental Assessment, Assistant Secretary for Environment, of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

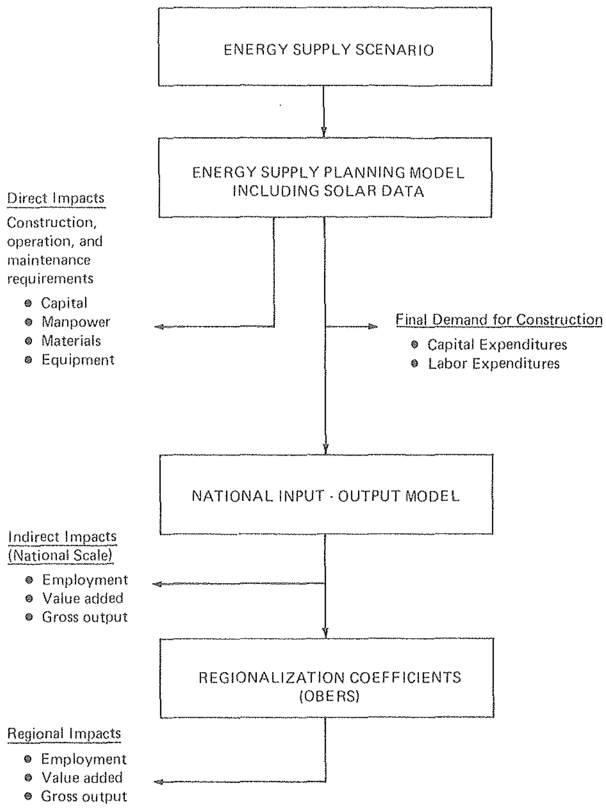

Fig. 1. Analytic methodology for estimating direct and indirect economic impacts. (XBL 8012-2575)

Bureau of Economic Analysis[2] (BEA) and updated to 1972 at LBL. During 1980 we further updated the model to reflect 1977 prices. In addition we provided the model with income and employment coefficients that make use of the Bureau of Labor Statistics projections of changes in labor productivity.[3] We also began to update the 1972 BEA national table to 1977 in order to use this as the basis for our I-O model.

The third major improvement to our models was to revise the method we used to break down the indirect impacts from the national totals to the ten federal regions. The national impacts are calculated for about forty sectors of the economy. We used the interim revisions to the Office of Business Economics and Economic Research Service (OBERS) projections of earnings by state[4] to determine regionalization coefficients for each of these sectors. A report generator was written that prints tables of the regional output, income, and employment.

Analysis of Scenarios

The two scenarios that we analysed for the TASE project[5] assumed different levels of solar energy utilization by the year 2000. The low solar (TASE 6) scenario has six quads and the high solar (TASE 14) had fourteen quads of primary fuel replaced by solar. Our major objective was to compare the economic impacts of the two scenarios. Our results are shown in Tables 1 and 2.

Most solar and renewable technologies are capital and labor intensive. Market penetration by these technologies will therefore require considerably more capital investment than conventional technologies. Their labor requirements for both construction and operation will be correspondingly larger. During the period from 1975 to 2000, the TASE 14 scenario calls for 2.8 million more employee-years of maintenance and operation labor than the TASE 6 scenario. Projected investment over the period totals $330 billion higher. These differences will be most noticeable between 1990 and 2000 when the penetration by the new technologies will be highest. The South Atlantic, Midwest, and Southwest regions will experience far higher investment and employment from increased use of solar energy than the other regions.

Indirect employment associated with industries supplying goods and services for energy construction activities in the TASE 14 scenario than in the TASE 6 scenario. Average annual indirect employment in the high-solar case between 1991 and 2000 amounts to 1.95 million employee-years, compared to 1.40 million employee-years in the low case.

In the RIIA analysis, we compared the indirect economic impacts of NEP 2 high- and NEP 2 low-energy scenarios.[6] These scenarios specify the levels of primary energy demand and supply for each type of fuel. The analysis estimated the potential capital and labor requirements for the two scenarios. The indirect impacts are also estimated and regionalized.

The NEP 2 low-energy scenario calls for $934 billion of capital investment between 1975 and 2000, whereas the NEP 2 High scenario requires $1058 billion in the same period. For both scenarios, investment increases during the 1976 to 1990 period and then declines during the last decade. Construction labor requirements for the low and high scenarios are 6.9 million employee-years and 7.8 million employee-years respectively. The majority (82%) of this increase in labor requirements is concentrated in the Southwest, South Atlantic, North Central, and Midwest regions.

Labor requirements for operation and maintenance of facilities in the NEP 2 high scenario amount to 34.2 million employee-years over the 25-year period, compared to 33.2 million employee-years in the low scenario.

Average annual indirect employment amounts to 908,000 in the high scenario, as compared to 705,000 in the low scenario during the last decade. Total employment, which includes direct construction, operation and maintenance, and indirect employment, increases from 2.4 million to 2.9 million in the high scenario. In the low scenario it increases from 2.4 million to 2.6 million and then declines to 2.5 million. The Midwest and South Atlantic regions will experience the largest indirect employment in both scenarios (24 and 16% of the national total), followed by the West, New York and New Jersey, and the Mid-Atlantic regions.

Table 1. Average annual employment impacts - TASE 6.

Capital Investment (10^9 $)	1976-1985		1986-1990		1991-2000	
	Solar	Total	Solar	Total	Solar	Total
Manpower	1.3	10.9	3.7	15.1	5.2	16.7
Materials	1.0	8.1	4.3	12.2	6.2	13.9
Equipment	.3	11.1	1.5	14.6	3.3	16.7
Other		14.0.		16.2		17.0
Total	3.2	44.1	11.4	58.1	17.8	64.3
Employment (10^3 man-years)						
Direct construction	37	331	110	459	156	516
Direct operation	53	1112	101	1370	214	1825
Indirect	111	1169	336	1462	442	1405
Total	201	2612	547	3291	812	3746
Indirect Employment (per 10^6 $ Capital Investment)						
In materials, equipment and other costs	36.2	33.4	30.9	29.5	26.1	25.1
In manpower	43.1	43.3	38.9	38.1	32.9	32.9
Employment (per 10^6 Total Capital Investment)						
Direct	11.6	7.5	9.7	7.9	8.8	8.0
Indirect	38.4	35.1	33.0	31.7	27.6	27.1
Indirect/Direct	3.3	4.7	3.4	4.0	3.1	3.4

Table 2. Average annual employment impacts - TASE 14.

Capital Investment (10^9 $)	1976-1985		1986-1990		1991-2000	
	Solar	Total	Solar	Total	Solar	Total
Manpower	2.8	12.2	8.8	19.7	10.5	19.8
Materials	2.3	9.2	10.1	17.6	15.3	22.0
Equipment	0.8	11.4	5.1	17.6	11.5	22.2
Other	1.2	14.4	4.7	18.5	10.5	22.4
Total	7.1	47.2	28.7	73.4	47.8	86.4
Employment (10^3 man-years)						
Direct construction	82	369	264	597	397	689
Direct operation	80	1134	182	1432	437	1978
Indirect	244	1307	843	1916	1179	1954
Total	406	2810	1289	3945	2013	4621
Indirect Employment (per 10^6 $ Capital Investment						
In materials, equipment and other costs	39.1	33.7	30.7	29.8	25.6	25.2
In manpower	43.2	43.2	38.1	38.1	32.9	33.0
Employment (per 10^6 Total Capital Investment)						
Direct	11.5	7.8	9.2	8.1	8.3	8.0
Indirect	38.6	36.3	32.7	31.8	27.4	27.1
Indirect/Direct	3.4	4.7	3.6	3.9	3.3	3.4

PLANNED ACTIVITIES IN FY 1981

We are planning to perform an integrated analysis of the effects of energy development in the West. As part of this study, we will estimate the potential direct and indirect economic impacts, and we will continue updating the 1972 BEA national input-output table to 1977. Using this national table, we will contruct tables for California and other western states.

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ORGANIZATIONAL, INTERFACE AND FINANCIAL BARRIERS TO THE COMMERCIAL DEVELOPMENT OF COMMUNITY ENERGY SYSTEMS*†

R. Schladale and R. Ritschard

INTRODUCTION

At the present time, the United States is engaged in a vigorous search for new energy supplies. Community energy systems are small-scale technologies capable of providing new sources of supply. Most of these technologies are fully developed, but none has been commercialized to meet more than a fraction of a percent of U.S. energy demand. The purpose of this study is to identify the barriers that groups and individuals will face when attempting to commercialize community energy systems.

The energy systems studied were: municipal solid waste (MSW); small-scale wind; industrial cogeneration; and residential photovoltaics. The scope of the barriers was restricted to three general areas: (1) organization barriers, (2) interface barriers, and (3) finanical and investment barriers.

Organizational barriers stem from deficiencies in organizations that attempt to develop a community energy resource, and may consist of a lack of awareness of opportunities; a lack of familiarity with energy technology; an inability to finance a feasibility study; or other factors.

Interface barriers cover a broad range of problems that arise when an organization seeking to develop a community energy system must interact with other organizations whose institutional policies and procedures were developed to meet an earlier set of conditions, i.e., before the advent of community energy systems. Consequently, smooth interaction may be difficult, and current policies and procedures may have to be revised to facilitate the growth of the new systems.

Finally, financial and investment barriers stem from the fact that new energy systems--although technologically proven in laboratories and demonstration projects--have not been tested under actual commercial market conditions. Consequently, new energy systems are deemed risky and investors will either avoid making commitments to them, or will do so only after attaching a high risk premium to their interest rate.

MAJOR FINDINGS

The major conclusions of this institutional study are given below and are organized into three categories: organizational, interface, and financial barriers.

Organizational Barriers

With regard to organizational barriers, the following are especially important:

- Municipalities need financial assistance to cover prebonding costs in the development of an MSW facility. These costs may total several million dollars, an amount that few municipalities have at their immediate disposal.

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† Condensed from R. Schladale and R. Ritschard, Organizational, Interface and Financial Barriers to the Commercial Development of Community Energy Systems, Lawrence Berkeley Laboratory report LBL-11188, August 1980.

- Municipalities may also require state assistance to ensure an adequate fuel supply. The state should establish wastesheds for each MSW project.

- Better information, education, and assistance should be made available to industrial management in order to accelerate the development of cogeneration.

- Neither residential homeowners nor homebuilders are very likely to possess the knowledge or skills necessary to install a photovoltaic system. The development of standardized, mass-produced technologies might need to be subsidized by government. Direct involvement by electric utilities or some other brokerage firm might be necessary.

These barriers are neither new nor particularly dramatic, but may merit more attention than they have heretofore received.

Interface Barriers

The issues involved in the interfacing of community energy systems with electric utilities have received considerable attention since the passage of the Public Utilities Regulatory Policies Act of 1978. Much progress has been made in developing regulations and purchase prices that make the scale of energy and capacity to utilities an attractive proposition. The Federal Energy Regulatory Commission and a number of state public utility commissions have been very effective in this regard.

Many interfacing issues and regulations remain in a state of flux, and further refinements to various policies are possible. Most of the recently developed policies were structured with the "firm types" of community energy systems--cogeneration and MSW--in mind. The applicability of these regulations for non-firm systems, such as wind and photovoltaics, is uncertain, although different provisions will be required in some policies, such as those governing payment for capacity cost.

Among the issues to which attention will be paid in the immediate future are:

- How reliable a small power facility must be to receive capacity payments; during what periods must power be available; and how should capacity payments be made for non-firm power (at what rate, and under what regulations)?

- Are small facilities dispatchable to obtain maximum capacity payments from the utility?

- The level of control that the utility has over a private developer's plans for a new community energy system is an important issue. The question includes whether the utility can demand special system-protection equipment or other special facilities. If so, who will decide whether demands for such equipment are reasonable?

- There are possible difficulties for cogenerators in obtaining exemptions to the Power Plant and Industrial Fuel Use Act of 1978 in order to burn natural gas. An issue is whether the cogenerators should pay the same prices and hold the same priority for natural gas that electric utilities do.

- Who will pay for necessary emissions offsets for new cogeneration and MSW facilities?

The authors feel that each of these issues will ultimately be decided in a manner conducive to further commericalization of community energy systems. The regulatory process may be slower than some would wish, but little experience exists with interfacing technologies other than cogeneration. It would be unwise to impose regulatory changes whose effects could upset the smooth operation of the large utilities on which society relies. Moreover, rapid changes in the structure of the electricity industry might be unacceptable to politically powerful forces in state legislatures and Congress.

Financial Barriers

The central difficulties that developers of community energy systems face in obtaining sufficient investment capital are: (1) the perceived risk of the new technologies; and (2) their relatively high cost compared to the historical cost of conventional power generating facilities. The recent cost increases for fossil fuels have made community energy systems much more competitive, although in most cases fossil fuel power plants still produce cheaper power. However, over the long term, it is clear that fossil fuel supplies will diminish and rise in price. Thus, commercialization of alternatives must be accelerated now, and for this reason, various political bodies are willing to provide public subsidies to accomplish it.

Municipal Solid Wastes

The major financial barriers to the development of municipal solid waste plants are the need to offer higher interest rates to bondholders because of project risk and the possibility of unexpected costs stemming from new emissions control regulations. Federal or state governments could provide guarantees to bondholders, and thus reduce the project risk; or they could provide grants that would directly reduce the project cost. Either would make financing an MSW project more feasible, but neither option has yet been enacted anywhere.

Wind

The major financial barrier for wind developers is the lack of start-up capital. This problem may be overcome through loans from the Small Business Administration, but the analysis given previously suggests that the funds currently available may be inadequate for this purpose.

Industrial Cogeneration

Cogeneration has received less than maximum investment in the past because its return on investment was considered too low. Because fuel prices have doubled during the past year, this situation has changed. Cogeneration now offers attractive returns and no additional subsidies for it are proposed in this study. However, if tight credit should prevail in the future, the provision of low-interest loans in place of currently available tax credits might be useful.

Residential Photovoltaics

For photovoltaics, the central barrier is system cost. If rooftop photovoltaic systems are to become competitive, they will require substantial subsidies in the form of low-interest, extended-term loans, as well as tax credits. The cost per kilowatt-hour of photovoltaic electricity subsidized may run as much as thirty times the cost per kilowatt-hour of cogeneration subsidized, even assuming that the Department of Energy's 1985 goal of 50¢/watt for solar cells is achieved. Of course, an important reason for accepting high photovoltaic subsidies is that cogeneration potential--as well as that of virtually every other source--is limited.

Summary

Three general observations regarding community energy systems may be distilled from this study. First, although many barriers exist to the commercialization of the systems, few, if any, appear unresolvable. Perhaps most challenging will be the problem of expanding the use of cogeneration and municipal solid waste, while at the same time maintaining or improving ambient air quality. Second, the financial subsidies required to make community systems competitive are not extraordinary. Indeed, with the exception of photovoltaics, they should not amount to more than about 10% of the capital cost of the new systems, and mass production may elminate the need for subsidies altogether in the future. Third, the administrative and regulatory procedures required to make community energy systems viable appear to be taking shape in a positive and timely fashion.

PLANNED ACTIVITIES IN FY 1981

This work was concluded in FY 1980 and will not continue in FY 1981.

COMMERCIALIZATION OF SOLAR ENERGY BY REGULATED UTILITIES*

E. Kahn, P. Benenson, and B. Brown

INTRODUCTION

In this project, we examine the role of regulated public utilities as financial intermediaries in the commercialization of solar energy. First we analyze the effect of various economic incentives offered by utilities to consumers for solar investments. Second we employ utility financial flow analysis to study the financial impact on utilities of solar incentive programs.

These incentive proposals are needed because public utility rates, typically set below marginal cost, reduce the value of solar investment. Moreover, incentives may enable utilities to avoid unprofitable energy demand that can be served less expensively by solar technology. Residential water heating is one end use for which this may be possible. Instead of investing in high-cost new supply facilities, utilities and their customers may benefit by channelling funds into financial incentives for domestic solar water heating. This issue is treated more fully elsewhere.[1]

* This work was supported by the Market Development Branch, Active Systems Division, Office of Solar Applications, U.S. Department of Energy under Contract No. W-7405-ENG-48.

ACCOMPLISHMENTS DURING FY 1980

During FY 1980 a large collection of potential incentives was extracted from the California Public Utilities Commission hearing record on this subject. These incentives were organized into three generic categories: (1) cash payments or bill credits, (2) interest subsidies and favorable loan terms, and (3) direct utility investment. This categorization was made from the perspective of the potential solar adopter. Questions relating to the cost justification and allocation of these incentives are treated in less detail.

Analysis of Financial Incentives

The generic solar incentives can be compared by present-value methods. Payments spread out over time can be related to the present through the following definition of present value (PV)

$$PV = \sum \left[\frac{PMT_i}{(1+r)^i} \right]$$

where PMT_i = payment in period i

r = discount rate.

Since this valuation depends strongly on the discount rate, r, and since r will vary in different circumstances, a parametric approach is adopted.

The present value of bill credits or periodic payments is simple to calculate. A consumer decision to invest in solar water heating would result if the present value of the incentive plus the present value of the energy savings exceeded the cost.

Loan incentives are more complicated. One popular form of such incentives is a zero-interest loan with delayed repayment. The critical feature of this approach is that the future value of energy savings need only be greater than the present value of the loan principal for the investment to be economic. The major uncertainty in this approach is the number of years until repayment is required. In the programs adopted to date this has averaged between five and ten years. The value of delayed repayment, zero interest loans can be seen in Figure 1. The graph assumes that solar water heating displaces 3000 kWh/year of electricity. The price of that electricity, p, ranges from 5-7 cents/kWh and the number of years to repayment is represented by the variable n. For a given n and p, the value of savings depends upon a discount rate (x-axis). For example, where n = 7, p = $0.06/ kWh and the discount rate is 15% or more, then the future value is $2500 or more. If the loan obligation were $2500 or less, then the investment is economic.

Direct investment programs are more straightforward. The main issue in this case is cost justification, since the incentive is typically the most expensive of all.

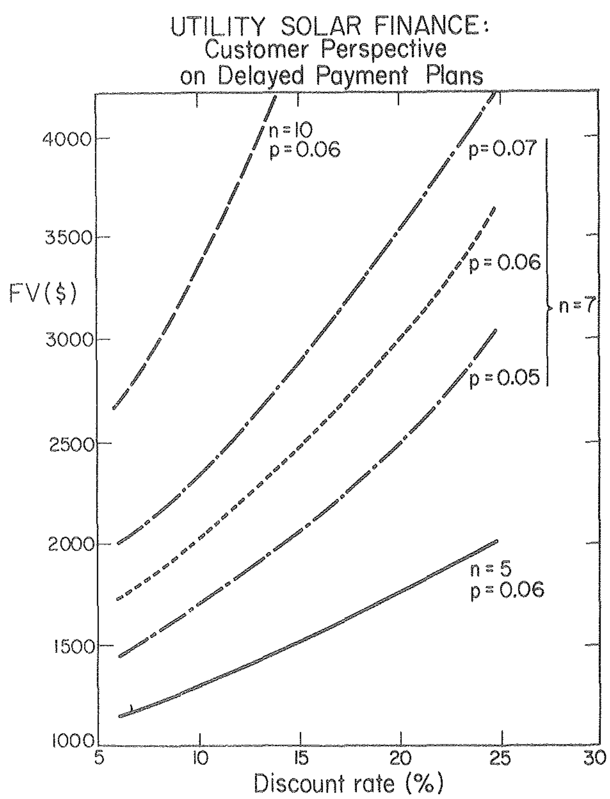

Fig. 1. Customer perspective on delayed payment plans. (XBL 803-424)

Utility Financial Impacts

Regulated public utilities face a variety of risks from their investment activity. These are reviewed in general and with regard to impacts from solar incentive programs. Particular attention is given to risk of competition, risk in the common equity market, risk in the bond market, interest-rate risk, inflation risk, and regulatory risk. Methods are developed to quantify the probability of negative utility cash flow. These methods are applied to recent financial data for a sample of utility companies. Various specifications of the basic model are compared to the corresponding bond ratings.

Analysis of Financial Simulation

The purpose of the simulation model is to estimate quantitatively the financial impacts of investments in conservation and solar energy on an electric or gas utility. The analysis is from the utility's viewpoint, and is microeconomic in scope; economy-wide parameters, such as energy demand, are assumed rather than internally determined. The analysis compares investments in conservation and solar energy with investments of corresponding magnitude in power plant construction. The calculations are made with a financial simulation model of a utility developed at the Environmental Defense Fund by Daniel Kirshner. The model is on the LBL computer system and is operated at LBL.

The model requires detailed inputs from the user regarding the present financial situation of the utility (e.g., average book life of the plant in the base year, amount of common and preferred stock, etc.). These data and the assumed investment plans are used to estimate the financial flows through the utility and to generate the balance sheet, income statement, sources and uses of funds, state and federal taxes, and other financial statistics for future years.

Such a computational model for estimating financial impacts is required because of the complexity of the regulatory and accounting options to which the utilities are exposed, such as normalization or flowthrough of accelerated depreciation and investment tax credits, construction work in progress in the rate base, and/or allowance for funds used during construction. The picture is complicated by several factors: (1) the maintenance of at least three sets of books by the utilities (one for stockholders, another for income taxes, and a third for regulatory purposes); (2) by the time in the asset life at which the impact is measured; and (3) by the fact that different construction projects often have different start and completion dates. The model accounts for these options and records the impacts according to the stockholder and regulatory sets of books. A schematic of the financial relationships that comprise the model is presented in Figure 2.

Some essential parameters are determined by market activity or by the regulatory process. Since this activity is beyond the model's scope, the assumption of their values introduces a static

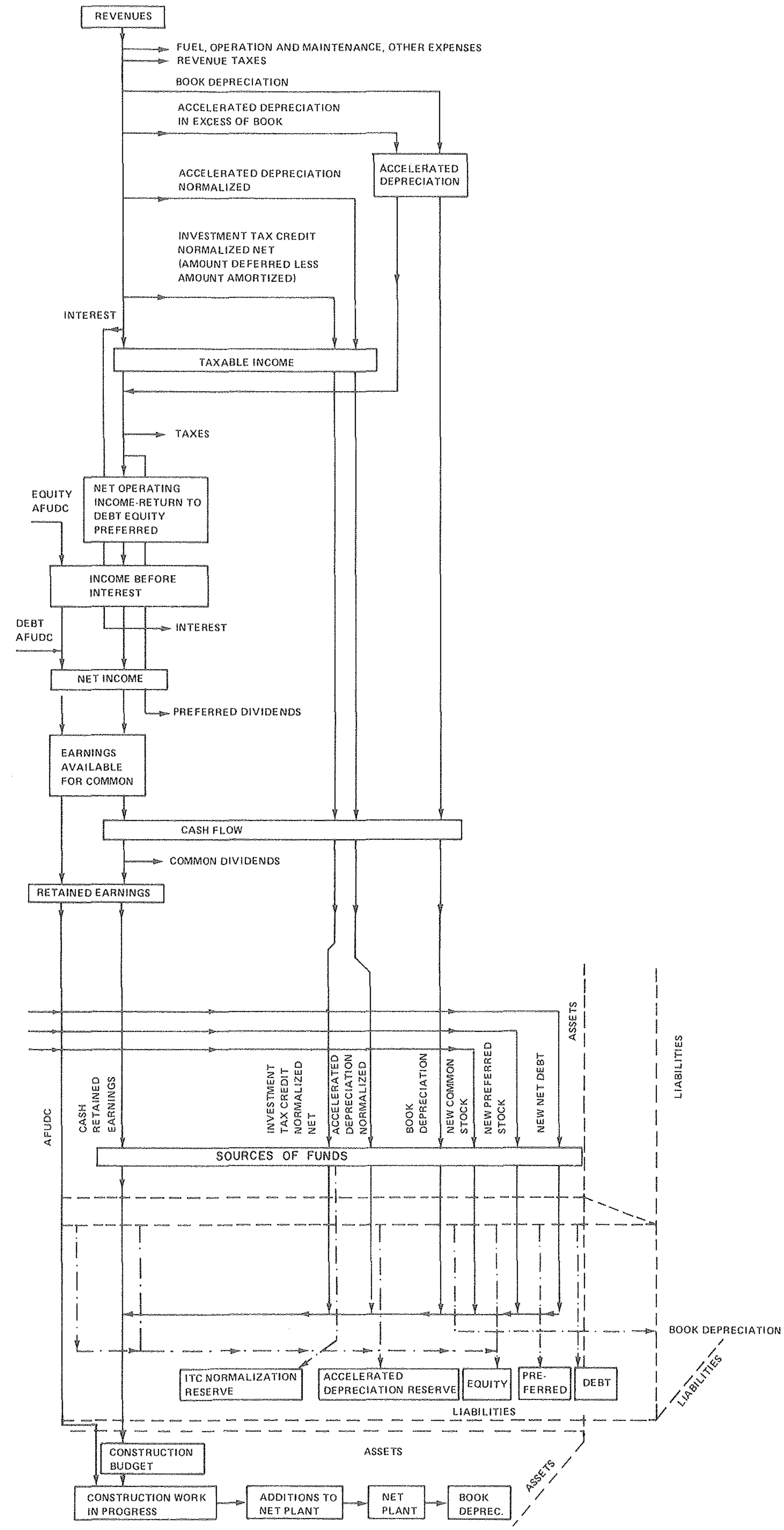

Fig. 2. Utility financial flows. (XBL 8010-4440)

treatment to what is determined dynamically in practice. Examples of such assumptions are electricity sales; the allowed rate of return on rate base and its equality with the realized rate; and the equality of fuel costs with fuel cost adjustments.

Two groups of cases are examined. The first, consisting of seven cases, begins with a base case of values approximating the present financial position of the Pacific Gas and Electric Company (PG&E). A general construction program of $1 billion per year, escalating at 10% per annum, is also assumed. The conservation cases differ from the base case by the addition of a ten-year, $100 million per year investment program in energy conservation equipment (construed broadly to include solar water heaters). They are depreciated in one case but not in another. In both, fuel costs are reduced to account for energy conservation. The power plant construction cases involve a substitution of the conservation expenditures by investments of equal amount and duration in power plant construction. The last two cases combine both investment programs with the power plant expenditures delayed to account for reduced energy demand from energy conservation. For this group of cases, the results show no major differences in financial variables examined. Ranking the cases is therefore difficult.

The second group, consisting of five cases, was designed to accentuate the differences between the impacts of the conservation and power plant investment paths. For the revised base case, the general construction expenditures were reduced to $500 million per year. The expenditures for conservation and power plant construction were increased to $200 million annually for ten years, and the conservation expenditures were depreciated.

A summary of the results for two of the five cases is presented in Table 1. Federal income tax is lower in the conservation case than in the power plant case because depreciation expenses can be claimed immediately, whereas for power plants they are delayed until the plant enters the rate base. The conservation case has a higher ratio of internal to total financing, a greater cash flow, and higher cash earnings per share. For many of the other impacts examined, there was little difference among the cases.

Table 1. Summary results of financial impacts from alternative investments.

Financial Category		Conservation $\$200 \times 10^6$/year (depreciated)	Power Plant $\$200 \times 10^6$/year
Federal income tax (10^6 \$)	1980	17.00	31.00
	1983	28.00	63.00
	1986	90.00	57.00
	1989	163.00	129.00
	1992	293.00	331.00
	1995	406.00	454.00
	1998	522.00	619.00
Cash earnings per share ($)	1980	3.44	3.44
	1983	3.66	3.62
	1986	3.99	2.79
	1989	4.50	3.35
	1992	5.41	4.90
	1995	6.75	6.09
	1998	9.30	8.19
Cash flow (10^6 \$)	1980	300.00	288.00
	1983	499.00	417.00
	1986	733.00	567.00
	1989	1015.00	918.00
	1992	1309.00	1354.00
	1995	1695.00	1757.00
	1998	2196.00	2310.00
Internal/total financing (%)	1980	22.80	29.10
	1983	34.00	34.20
	1986	43.10	15.20
	1989	50.60	41.70
	1992	61.80	59.10
	1995	63.80	63.00
	1998	66.00	67.20

The second group shows that the type of investment and the time path of expenditures can significantly impact a utility's financial situation. The conservation expenditures appear more advantageous because they can be depreciated and recovered more rapidly, but they must be of sufficient magnitude relative to the assets and expenditures of the utility to make an appreciable difference. These results are preliminary and await several modeling refinements and confirmation by industry personnel before they can be relied on for policy recommendations.

PLANNED ACTIVITIES FOR FY 1981

Financial simulation analysis of the solar incentives adopted by the California Public Utilities Commission will be conducted.[2] In addition, analysis of rate-making implications will be pursued. Utilities with large construction programs and/or in poor financial condition will also be studied.

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POWER SYSTEM RELIABILITY*

D. Levy and E. Kahn

INTRODUCTION

Numerical methods have historically been used to calculate reliability indices like loss-of-load probability (LOLP) for electric power generation systems.[1] For many purposes, however, numerical methods are a cumbersome means of computation. In capacity expansion models, for example, 20-year planning horizons are evaluated over a wide range of input assumptions. To reduce computational complexity and add conceptual perspective, several authors have studied analytic methods for approximating the numerical calculations. The most successful of these methods is an expansion based on the normal probability distribution, its moments and derivatives.[2-6] There are several variations on this approach, depending on the exact form of expansion used. Individual forms of the series are associated with Edgeworth and Gram-Charlier.[7]

The purpose of this research is to systematically investigate the accuracy of these methods with particular attention to power systems of 5000 MW and less. Two approaches are used: (1) a numerical approach with specific examples, and (2) an analytic approach in which underlying functional dependences are examined.

The most successful applications of the Edgeworth expansion and related approaches have been to large systems, typically in excess of 15,000 MW capacity. Even for systems of this size, if the average forced outage rate (FOR) is very low, the series can have disturbing properties and limited accuracy.[8] Since the method relies in part on central-limit theorem arguments, it can be expected to work well only when the number of random variables, i.e., generators, is large. Hence, there is reason to believe that the Edgeworth expansion will be less useful to approximate small systems than large ones.

ACCOMPLISHMENTS DURING FY 1980

Numerical Simulation Studies

Due to the substantial differences among electric utility systems it is important to examine particular configurations to test the accuracy of the Edgeworth approximation. To perform these tests, the Edgeworth series is written as a four-term expression, where each term has the opposite sign from the preceding term.[8] The standard numerical calculation of LOLP is compared to the analytic series. Typical results are shown in Figures 1-4 below.

Figure 1 shows a well-behaved case in which accuracy improves with additional terms and the approximation fits the numerical calculation well. In Figure 2 the same system is evaluated at a lower forced outage rate (FOR) for the individual generators in the system. Here oscillations and pathologies appear. At several points the series becomes ill-defined because the probability distribution takes on negative values. In Figures 3 and 4 the average forced outage rates for generators are based on data collected by Edison Electric Institute (EEI). Here the problems are not quite so extreme as in Figure 2. Accuracy, however, is limited in certain regions and does not necessarily improve with additional terms. Figure 3 is based on a very small system of less than 1000 MW and only 14 units. Figure 4 shows the effect of adding one large unit (1150 MW) to a system of just over 4000 MW. To

*This work was supported by the Solar Energy Research Institute through the Assistant Secretary for Conservation and Solar Energy, Office of Planning and Technology Transfer, U.S. Department of Energy under Contract No. W-7405-ENG-48.

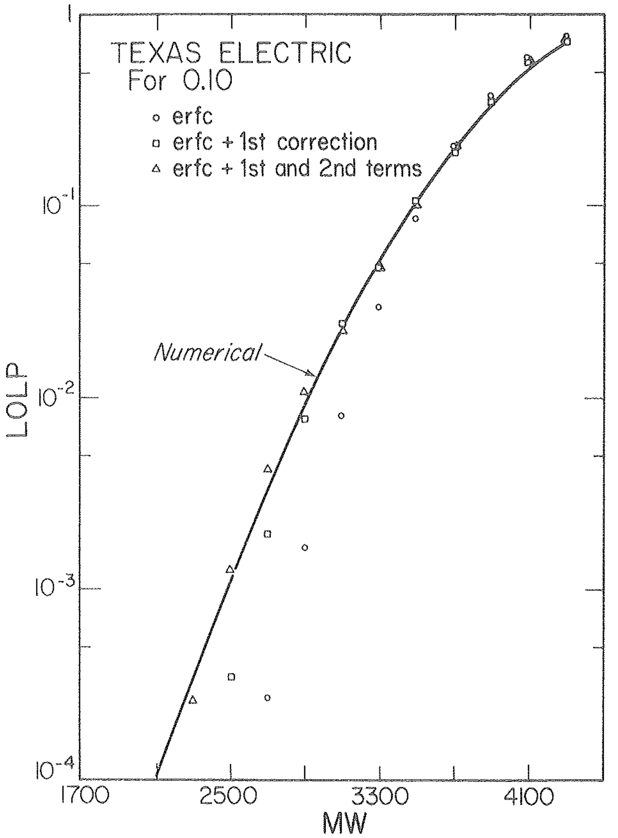

Fig. 1. LOLP plotted against generating capacity of Texas Electric System at FOR = 0.10. Edgeworth expansion error functions compared to numerical results. The acronym erfc stands for "the complementary error function." (XBL 803-432)

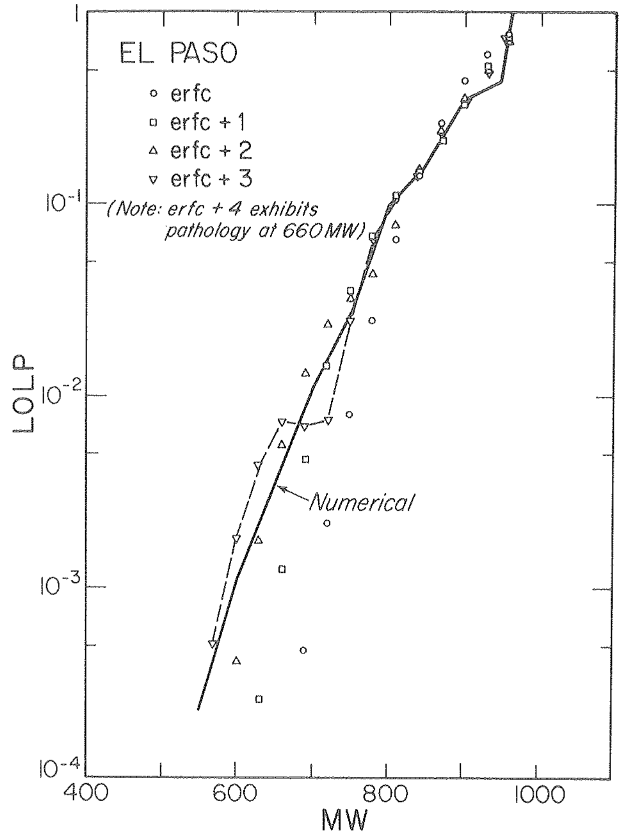

Fig. 3. LOLP plotted against capacity of El Paso Electric Co. system (based on Edison Electric Institute forced outage rates); Edgeworth expansion error functions compared to numerical results. (XBL 803-428)

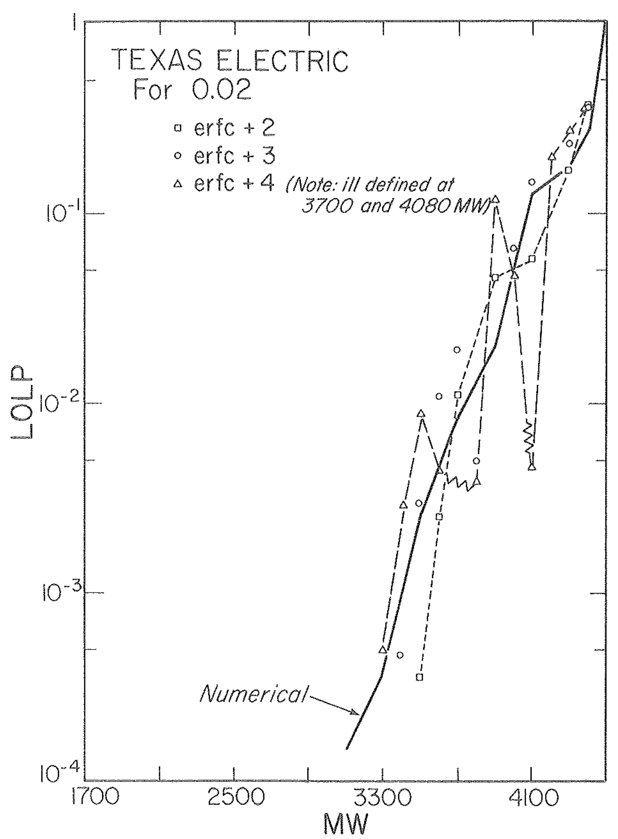

Fig. 2. Same as Fig. 1 except with FOR = 0.02. (XBL 803-431)

study these results in a more general setting, the analytic properties of the Edgeworth series were examined more closely.

Analytic Results

Edgeworth-type expansions are usually appropriate when the underlying random variables take on continuous values.[9] This condition is violated in the case of most LOLP calculations where the generator's output characteristics are represented by probability distributions that limit the variables to discrete values only. Usually units are assumed to be either on or off in the two-state model. Where partial outages are considered, the standard model is again discrete rather than continuous. The underlying discrete probability distributions used to describe generators give rise to an aggregate probability distribution that is not continuous and that is referred to as a lattice-type probability distribution. In the limit of an infinite number of generators ($N \rightarrow \infty$), lattice as well as continuous probability distributions can be accurately described with the central-limit theorem.[9,10] In practice, the number of generators

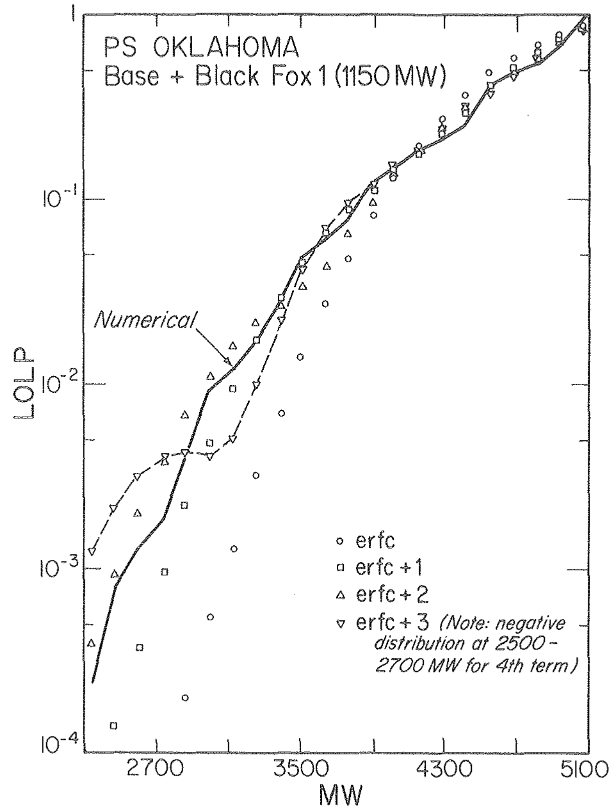

Fig. 4. LOLP plot for Public Service Co. of Oklahoma after addition of 1150 MW nuclear unit (based on Edison Electric Institute forced outage rates). (XBL 803-429)

(N), is finite so corrections to the central-limit theorem's normal distribution need to be considered. To calculate these corrections, most authors have used an Edgeworth series even though, as we have remarked, such expansions are inappropriate for lattice distributions and simple criteria, for their accuracy are lacking.

The essential problem with the Edgeworth expansion is that higher order terms, depending on higher moments of the underlying distribution function, can take on large values. For the case of small forced outage rates L_i and a finite number of generators N, each with capacity α_i, the following condition on the N + 1 unit will give the greatest accuracy:

$$\alpha_{N+1} = \sum_{i=1}^{N} \alpha_i^3 L_i / \sum_{i=1}^{N} \alpha_i^2 L_i \quad .$$

This expression will generalize to the case where forced outage rates are so low that convergence of the series will not occur. This condition is

$$\sum_{i=1}^{N} L_i < 1 \quad .$$

PLANNED ACTIVITIES FOR FY 1981

In FY 1981 several other approaches to analytic modeling of LOLP will be attempted. Based on the results of FY 1980 investigations, the new methods will take explicit account of the fundamentally discrete nature of the problem. One approach will use the Pearson-type system of frequency curves. In addition, new methods will take explicit account of load uncertainties in the LOLP calculation.

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ACID MINE DRAINAGE IMPACTS ON GROUNDWATER *

M. Henriquez and J. Sathaye

INTRODUCTION

This study is one of the many technology assessment programs sponsored by the Technology Assessment Division within the Assistant Secretary for Environment. The study was conducted jointly with two other national laboratories, Argonne National Laboratory (ANL) and Oak Ridge National Laboratory (ORNL), which were responsible for analyzing the potential groundwater problems caused by acid mine wastes due to projected increases in coal mining activity.

Past experience has shown that rapid exploitation of coal resources results in long-term degradation of groundwater resources. The effects on the Appalachian region are well-documented. The adverse effects from unrestrained mining, such as acid mine drainage (AMD), and from unproductive reclaimed strip mine sites, are still felt decades after mining has ceased. Future major expansion of coal mining is expected in the Appalachian region as well as in the Western U.S.

In general, the new coal mining techniques are not expected to have significantly different impacts than those that occur with mining activity today, however, their magnitudes per ton of coal mined may be smaller because of improvements in mining techniques and because of soil alkalinity in the Western U.S. In this study, we have evaluated the relative magnitudes of the damages caused by acid wastes from both deep and surface mining in various U.S. regions.

The damage caused by acid mine waste can be both chemical and hydrological, depending on the various coal mining techniques and groundwater features. Furthermore, in many instances both types of damages are closely coupled, so that it is not possible to segregate their effects.

The magnitude of damage depends on coal mine characteristics and on groundwater characteristics. Mine geometry, relative transmissivity of spoil material, internal features, mine site, and type of operation all have an important role in determining the waste products generated from a coal mine. The extent to which the groundwater aquifers are affected will depend on the transmissivity and storage coefficient of each aquifer, the flow velocity, and the existing groundwater quality. The flow velocity is also influenced by the rate at which water is withdrawn from the system.

Acid mine wastes are formed when pyrite (FeS_2) oxidizes and dissolves in water to form sulfuric acid and ferric compounds. Pyrites and similar minerals are present in undisturbed coal seams. The process of coal mining exposes these compounds to air (oxygen); water movements through the exposed material then carry the oxidized pollutants to groundwater aquifers. For domestic or industrial users, AMD results in stains on laundry and in corrosion of pipes and engineering structures. Water containing AMD must be treated before use.

* This work was supported by the Technology Assessment Division, Office of Environment, U.S. Department of Energy under Contract No. W-7405-ENG-48.

ACCOMPLISHMENTS DURING FY 1980

Methodology

The specific purpose of this study was to estimate the potential impacts on groundwater due to projected nationwide deep and surface coal mining activity. As noted earlier, the acid mine waste impacts are specific to the type and form of mining, to the coal seam, and to the groundwater aquifer underlying or surrounding the coal. With the limited time and data available to us, it was not possible to establish a mine-specific pollutant flow model for each U.S. coal mine.

We have established a methodology which in the aggregate accounts for all the variables that can affect aquifer pollution due to coal mining. The analysis is conducted for each of 21 water resources regions, which were delineated by their hydrological and geological characteristics. Data on aquifer parameters, such as storage coefficient, transmissivity, and soil permeability are available from several U.S. Geological Survey (USG) documents.[1] Projected levels of coal extraction by county were provided by the Futures Group[2] for 1980, 1985, 1990, 1995, and 2000, using base year information for 1975. Pollutant- (AMD) loading information was also provided for surface and deep mining by each coal region.[3]

These data, along with the average groundwater flow velocity (which is computed for each water resource region) are combined to form a comparative index. This index provides a guide to the relative severity of impacts among different regions of the country. The index value is directly proportional to flow velocity, permeability, coal mining rates, acid waste discharges, storage coefficients, and inversely proportional to aquifer transmissivity.

The index is primarily a comparative tool and is formulated so that it fits the base year data available from USGS. Aquifers for which we calculate a significant and related impact for a given year correspond to those aquifers in which AMD is recognized to be a major problem, on the basis of field measurements done by USGS. These areas are shown in the maps for 1975 (Figs. 1 and 2).

Results

The accompanying maps (Figs. 3 and 4) show the index values for the year 2000. Index values greater than 1000 correspond to counties where severe impacts may be expected because of increased coal mining activity. For all these counties, the

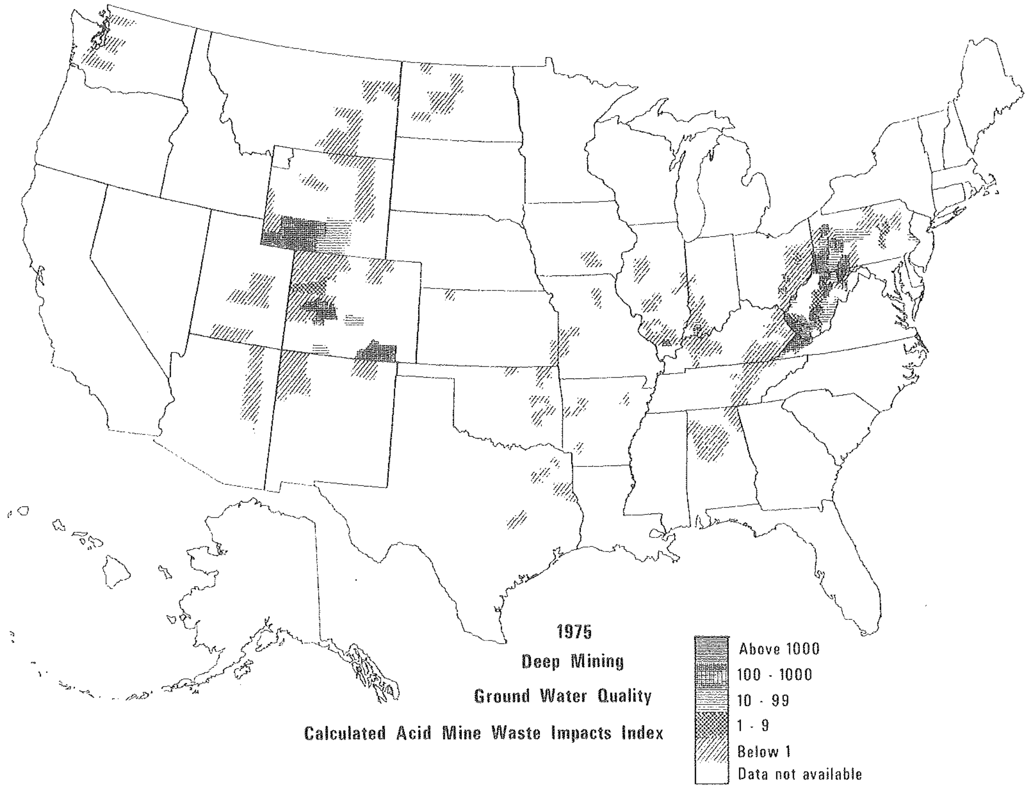

Fig. 1. 1975 calculated deep mining impacts. (XBL 8012-2441)

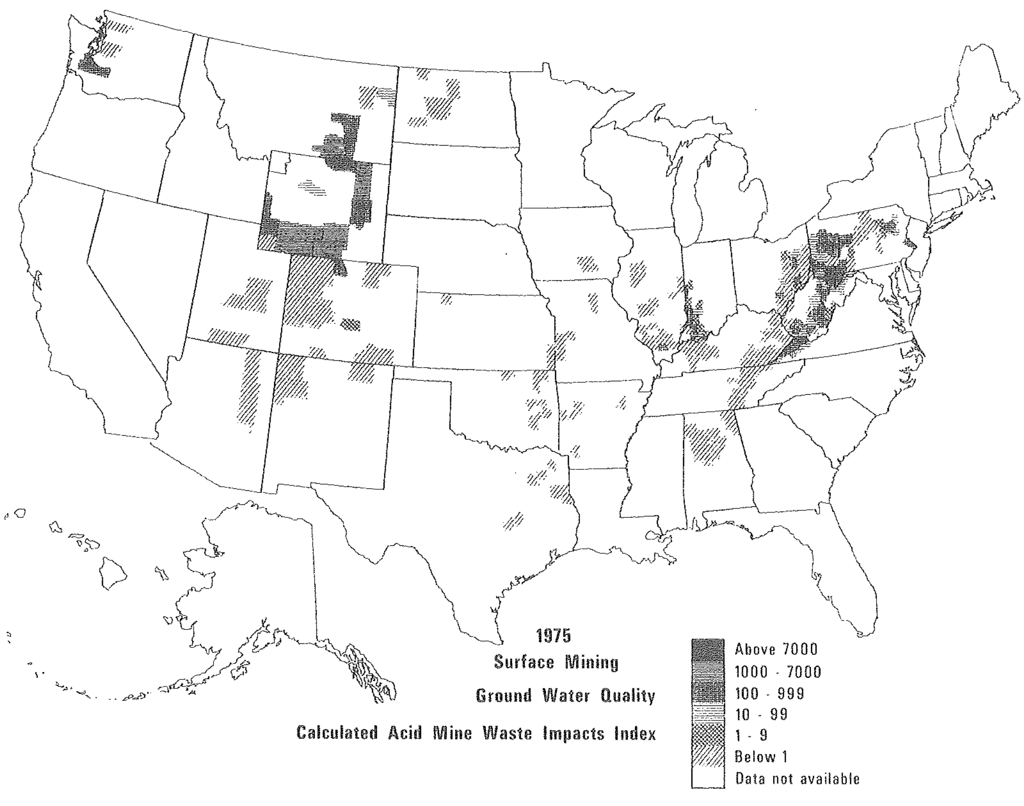

Fig. 2. 1975 calculated strip mining impacts. (XBL 8012-2442)

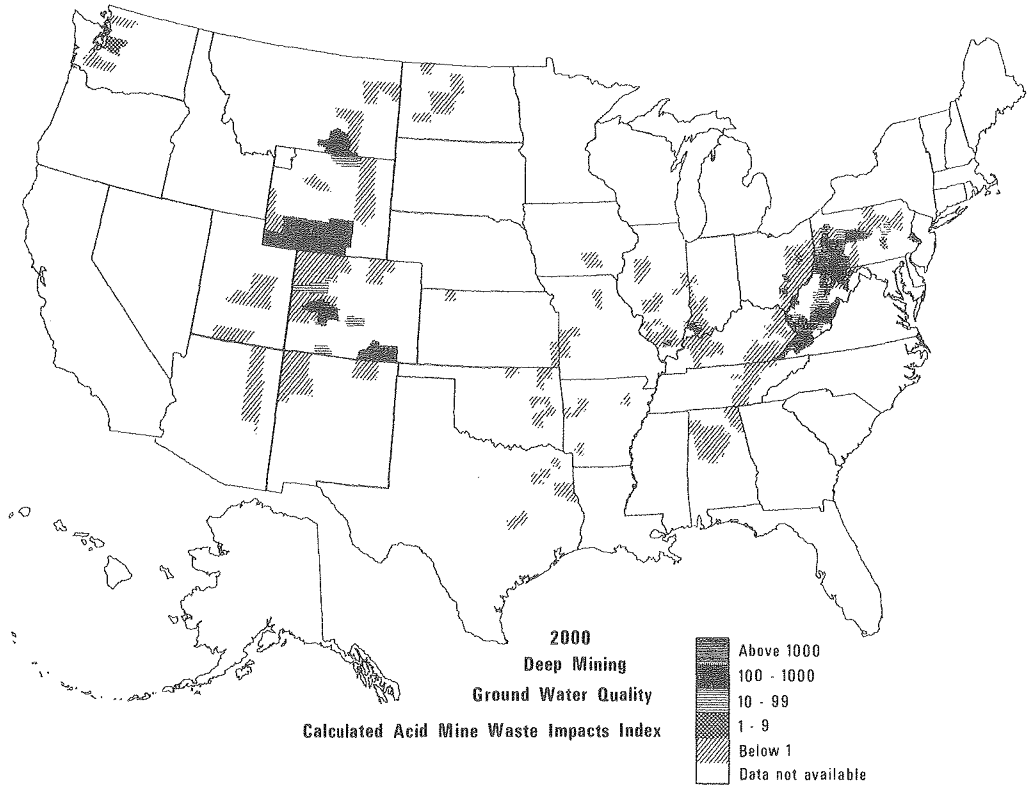

Fig. 3. 2000 calculated deep mining impacts. (XBL 8012-2443)

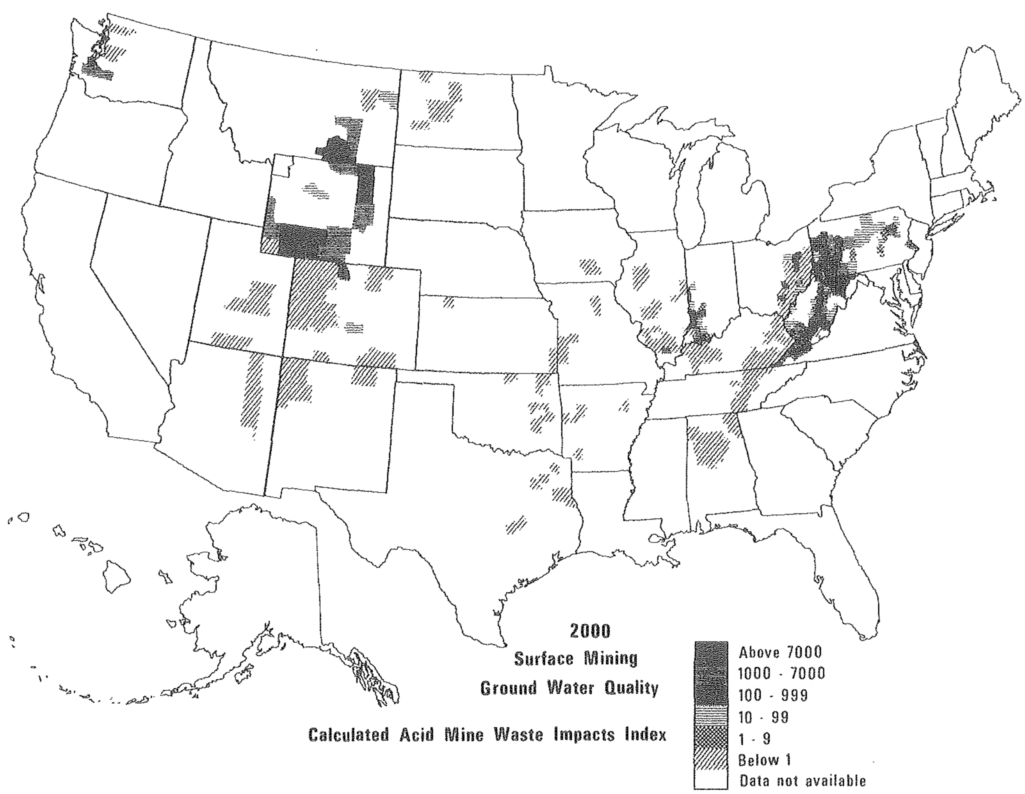

Fig. 4. 2001 calculated strip mining impacts. (XBL 8012-2444)

high level of coal mining activity is a more significant determinant of the environmental damage done than are the hydrological parameters. In other areas, where comparable amounts of AMD releases occur, e.g., the Ohio region and the Missouri region, different effects result due to the differences in groundwater hydrology.

The amount of potable water in the Ohio region is estimated at about 108,000 billion gallons in 1975, about 25% of Lake Ontario's liquid volume. Twenty-eight percent of the potable supply is in the Wabash and White subbasins, sites of high coal extraction. Acid mine drainage is a current problem in these basins along the Ohio-Pennsylvania border. The measured severity of the problem decreases further west. Groundwater systems in this area are highly permeable and are hydrologically connected to surface streams.

The Missouri basin has total aquifer storage of 150,000 billion cubic feet. Natural groundwater movement is in the direction of surface drainage, however, lateral movement in deep aquifers may be unrelated to surface drainage.

Table 1 shows the hydrological parameters for each basin. The AMD values used in our analysis are also shown. The 1975 index values for both surface and deep mines are roughly 60-80 for the Missouri region and 10-15 for the Ohio region.

These values agree with reported USGS measurements regarding groundwater quality. The values are similarly dispersed for the year 2000.

Index values are proportionately higher for increased coal extraction forecast for 2000. Average values for the Missouri region are 250 for surface mining versus 30 for the Ohio region. This indicates that both regions will face an increase in damage due to coal mining although the level of impacts will still be lower in Ohio. The deep mining impacts do not increase very much in both regions. Index values (70 and 22) change little from 1975.

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2. D. Canete, "Assessment of Increased Coal Production and Distribution," Futures Group Memorandum (unpublished), Washington, D.C., January 1980.

3. Mitre Corp., "Annual Environmental Analysis Report," vol. 1, Simulation Data Base for the Assistant Administration for Environment and Safety, (Washington, D.C.: MITRE Corp., 1977).

Table 1. Values of key parameters.

Region	Transmissivity (gallons) per day)	Storage coefficient	Permeability (gallons/ day/ft.^{2})	Velocity (ft.^{3}/ sec)	AMD (tons/ 10^{12} Btu)	
					Surface	Deep
Missouri	1×10^6	0.080	20	33	6.9	67.7
Ohio	4×10^5	0.015	1500	433	6.9	67.7

ENHANCED OIL RECOVERY*

J. Sathaye and M. Milukas

INTRODUCTION

The environmental assessment of potential oil recovery by tertiary extraction methods is the primary objective of this study. This is a multilaboratory effort involving Brookhaven National Laboratory (BNL), Pacific Northwest Laboratory (PNL), and LBL, supported by the Technology Assessment Division of the Office of Environment. There are four basic methods of tertiary or enhanced oil recovery (EOR). These methods are steam flooding, fire flooding, gas injection, and chemical injection. These methods work by either reducing the oil viscosity or altering its surface tension, forces which tend to hold the oil in place.

Steam flooding, the first such technique to be applied, is the one EOR method to have reached the large-scale commercial use stage. Steam is injected into the reservoir, and the heat it carries lowers the oil's viscosity, thus improving recovery.

* This work was supported by the Technology Assessment Division, Office of the Environment, U.S. Department of Energy, under Contract no. W-7405-ENG-48.

Steam injection is carried out either as a cyclic process or on a continuous basis.

In fire flooding, a fraction of the oil in place is ignited while air is injected to maintain the combustion process. Water is injected sometimes, and it flashes to steam, helping to maintain a heat front which advances as the oil is removed from a production well.

Whereas thermal methods work primarily by lowering the viscosity of oil in place, chemical methods have as their main goal the reduction of interfacial tension between the oil in place and the sweeping fluid, which had been injected into the formation to decrease the oil's viscosity. This is accomplished with surfactants, polymers, and alkaline solutions.

The introduction of gases into an oil reservoir under high pressure has the desirable effect of vaporizing some of the hydrocarbons in the petroleum. This, in turn, acts favorably on the mobility of the reservoir fluids. Carbon dioxide is considered one of the most promising gases for use in this type of EOR operation.

EOR techniques at present account for about 4.5% of total daily U.S. oil production. Of the 385,000 bbl/day produced by EOR,[1] 296,000 or 77% are the result of steam applications. The next most promising techniques appear to be the gaseous methods with CO_2 floods the most important one. These gaseous applications resulted in another 75,000 bbl/day.

ACCOMPLISHMENTS DURING FY 1980

During FY 1980, a workshop was held on the environmental, economic, health, and safety aspects of EOR. The workshop was attended by experts in tertiary recovery from industry, government, public interest groups, consulting organizations, and academia.

A preliminary concern of the workshop participants was to agree on a reliable estimate of EOR production for the next twenty years. As with any new and rapidly developing technology, the issues and factors affecting production change rapidly. These are some major factors which could change current forecasts significantly:

- The development of EOR offshore and in Alaska is relatively unknown.
- The downhole steam generator technology could eliminate air pollution, thus removing one of the prime barriers to increasing oil recovery through steam injection.
- The windfall profits tax provides a tax incentive to EOR production for the next forty months; beyond that period, the industry representatives claim that the tax will hurt oil production from EOR.

Air pollution was an issue of major concern in one region: California. The boilers used to generate steam for injection in oil wells are a major source of sulfur oxide and nitrogen oxide emissions. Offsets for these emissions would have to be found under California law if these boilers are to continue to burn crude oil. The downhole steam generator would inject the steam and these gases into the oil wells, thus eliminating the need for air pollution control.

Groundwater pollution, often cited as the major concern about EOR, was downplayed as a major concern. In examining leakage of oil, other chemicals, and brine to groundwater, it is important to distinguish between pollutants due to tertiary recovery (which is the focus of this project), and those due to primary and secondary recovery. However, although there are no official records of groundwater contamination due to EOR, the hazard still exists and needs to be evaluated carefully.

Disposal of solid waste from scrubber sludge may be another major factor in restraining steam EOR production in California An appropriate hazardous waste-disposal site would have to be found to accept all the sludge with its heavy metals.

Shortage of trained manpower was cited as a major problem by industry representatives. Qualified engineers, technicians, and field personnel to work on EOR are in short supply and the problem was predicted to intensify with increased EOR activity.

PLANNED WORK FOR FY 1981

During FY 1981, we plan to concentrate on two major activities:

- Establishing a data base on EOR activities in various oil fields nationwide. This would include production levels, oil reservoir characteristics, and soil characteristics.
- Establishing a groundwater data base for areas where EOR activity is expected. Groundwater quality and proximity to water users can be estimated and monitored.

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GEOPRESSURED GEOTHERMAL RESOURCE OF THE TEXAS AND LOUISIANA GULF COAST: A TECHNOLOGY CHARACTERIZATION AND ENVIRONMENTAL ASSESSMENT*†

A. Usibelli, P. Deibler, and J. Sathaye

INTRODUCTION

This study examines two aspects of the Texas and Louisiana Gulf Coast geopressured geothermal resource: (1) the technological requirements for well drilling, well completion, and energy conversion, and (2) the environmental impacts of resource exploitation. The information contained in this study comes from the literature on geopressured geothermal research and from interviews and discussions with experts.

The technology characterization section of the report emphasizes those areas in which uncertainty exists and in which further research and development is needed. The environmental assessment section discusses all anticipated environmental impacts and focuses on the two largest potential problems: subsidence and brine disposal.

MAJOR FINDINGS

Technological Requirements

Nearly all aspects of geopressured well drilling and completion are similar or identical to techniques employed in conventional petroleum resource development. For those areas in which geopressured and conventional petroleum development vary, refinement of existing technique will be required. Experimentation will lead to use of the most appropriate mud and cement compositions. The greatest difficulty will be encountered in the development of monitoring devices adequate for extreme down-hole pressures. Accurate and safe drilling requires simultaneously obtaining information on a range of variables. In addition, in-situ sampling techniques require further basic and applied research in order to overcome current pressure limitations. A variety of completion methods, including both water well and petroleum well techniques, will be used experimentally in demonstrating resource feasibility. Additional experience will reduce the risk of blowouts and bad cementing, but as with conventional petroleum drilling, some risk will remain.

Energy embodied in the geopressured resource can be exploited in three different forms: the chemical energy of methane dissolved in the brine; the thermal energy in the form of geothermal heat; and the kinetic energy of high pressure fluids. The resource of major interest, however, is the methane contained in the extracted brines. Technologically, geopressured geothermal energy conversion is a hybrid of the conventional oil and gas and the geothermal electric industries. Development of major new techniques and technologies for geopressured resource development is not required. High brine flow rates coupled with the problems of erosion, scaling, and corrosion, however, will require refinement of both equipment and operating procedures. Disposal of brines into subsurface aquifers (2,000 to 5,000 feet deep) will not be technically difficult, although large volumes of spent brine at high pressure require careful management and monitoring of equipment.

Environmental Concerns

Surface subsidence resulting from geofluid withdrawal and the reinjection of spent brines into subsurface formations will be the two most difficult environmental aspects of resource development. In each case, the uncertainty is high. The severe adverse impacts of subsidence, or the inability to successfully reinject huge volumes of brine, may slow or halt commercial development of the resource.

The probability, magnitude, and rate of subsidence resulting from geopressured development is largely unknown. Experts disagree on the adequacy of current levels of theoretical knowledge for analyzing and predicting subsidence in the necessary site-specific manner. Some factors indicate a high potential for subsidence; others point to low potential. For instance, the extensive growth-faulting of the Gulf Coast may help limit the areal extent of subsidence. At the same time, the undercompacted sediments of geopressured reservoirs may enhance the probability of significant subsidence.

Geopressured rock testing is almost at a standstill until new samples can be obtained and data generated. Current simulation techniques cannot be refined until more data are available. Any analogy of geopressured subsidence with subsidence resulting from the extraction of geofluids (such as oil and gas, geothermal fluids, or groundwater), is far from precise. Its depth as well as its highly faulted sediments are unique features thought

* This study, conducted as part of a larger multilaboratory project to evaluate the technologies and environmental impacts of unconventional natural gas sources, was sponsored by the Technology Assessment Division within the Assistant Secretary for Environment's Office, U.S. DOE under Contract No. W-7405-ENG-48. Pacific Northwest Laboratory was responsible for evaluating tight sand, Devonian shale, and coal mine methane sources while LBL was responsible for the geopressured geothermal resource.

† Condensed from A. Usibelli, P. Deibler and J. Sathaye, The Geopressurized Geothermal Resource of the Texas and Louisiana Gulf Coast: A Technology Characterization and Environmental Assessment, Lawrence Berkeley Laboratory report LBL-11539, 1980.

to be determinants of subsidence. Efforts are now underway to standardize the nomenclature and testing procedures used by a variety of specialists from different disciplines. Increased emphasis will be placed on extensive testing of laboratory samples. The potential severity of geopressured subsidence in the low-lying Gulf Coast indicates that research should proceed in an unhurried but deliberate manner.

Spent brine is hot and chemically complex fluid that varies greatly in composition. Concentrations of heavy metals, organics, and trace elements frequently occur at levels far in excess of seawater concentrations and Environmental Protection Agency (EPA) toxicity standards. In an untreated form, discharge of this brine into terrestrial or aquatic ecosystems will cause major adverse biological impacts.

At present, reinjection of the waste brine into subsurface aquifers located above the producing formation is the only disposal method under serious consideration. Undesirable communication of the brine with adjacent fresh water formations, or with the ground surface, are risks that can be minimized with proper operating procedures. Control of reinjection pressures can aid in reducing the threat of environmental disruption resulting from fluid disposal. Surface disposal of brine to the Gulf of Mexico is more problematic. Disposal of hypersaline brines into the gulf from the Federal Strategic Petroleum Reserve (SPR) Program may provide useful data on dispersion patterns and possible impacts. Unfortunately, any disposal comparison is only partially realistic because of the different chemical and temperature characteristics of the two fluids. Brines probably cannot be dumped into the gulf except with intensive pretreatment.

Air quality, solid waste, noise, fault activation, and other environmental impacts have been mentioned in association with geopressured geothermal development. In each case either: the magnitude of the impact is small; the residuals are easily controlled; or, the probability of occurance is so small that impacts may be considered to be of second-order importance. Residual-monitoring programs should continue for existing and new test wells to enlarge the data base. Relative to subsidence and brine disposal, these impacts should not significantly affect resource development.

No geopressured wells have been drilled, or are planned, for the offshore Gulf Coast area. However, preliminary geological mapping of the offshore resource indicates several good prospect areas. But there are environmental, economic, legal, and institutional advantages and disadvantages to an offshore development strategy. From an environmental perspective, the impact of subsidence may be reduced through offshore development. Conversely, brine disposal may be more difficult unless adequate dispersion of brines can be achieved in the deep ocean areas beyond the outer continental shelf. Research is needed in certain areas to determine if an offshore development strategy should be pursued. The aim of this report is to discuss the pertinent issues and to indicate areas of research.

<u>Recommendations</u>

Technological

- Joint work on in-situ logging instruments for both geopressured and conventional geothermal wells should be encouraged.
- A range of well completion techniques should be tested in order to minimize drilling and completion risks.
- Full-scale testing of commercial production facilities--which include gas separators, hydraulic turbines, and geothermal electric units--should be conducted at the earliest possible time.

Environmental

- Funding for geopressured subsidence laboratory testing should be increased. The use of several laboratories, each with particular areas of expertise, should be encouraged.
- Communication between members of various disciplines working on subsidence research should be accelerated and research techniques and nomenclature should be standardized.
- Monitoring and analysis of the impacts of Gulf Coast disposal operations by the SPR should be closely scrutinized by researchers studying geopressured geothermal resources.
- Offshore brine disposal should be seriously studied as an option.
- The possibility of offshore development should be critically examined. A wide range of factors must be weighed in balancing the environmental, economic, legal and institutional advantages and disadvantages of such a strategy.

Table 1 is one of the study's environmental assessment matrices. The matrix is a qualitative summary of the subject areas considered in the environmental section. The assigned values attempt to balance diverse opinions expressed in the literature and the unpublished comments of researchers. Nonetheless, the choice of values often remains subjective. Because of the limitations of a ranking system with only three classifications, the correct characterization of a given aspect of resource development occasionally seemed to us to lie between two of the categories. However, this matrix may aid the reader in putting various aspects of geopressured development into perspective.

PLANNED ACTIVITIES IN FY 1981

Work may continue on this project in FY 1981.

Table 1. Summary of environmental assessment of geopressured geothermal extraction.

Impact Area	Analogy Oil/Gas	Analogy Geothermal	Analogy SPR*	Information Base	Experience Level	Research Basic	Research Applied	Magnitude	Mitigation	Uncertainty	Consensus
Subsidence											
Compaction	1	2	n.a.	2	3	x	x	n.a.	n.a.	2	2
Rock mechanics	2	2	n.a.	2	3	x	x	n.a.	n.a.	2	2
Shale dewatering	?	?	n.a.	2-3	3	x	x	n.a.	n.a.	1	3
Fault activation	2	2	n.a.	3	3	x	x	?	n.a.	1	2
Brine disposal											
Offshore-surface	2	3	2	3	3	x	x	1	3	1	2
Onshore-surface	2	2	3	2	3	n.a.	n.a.	1	3	3	1
Brine chemistry	2	2	2	2	n.a.		x	n.a.	n.a.	2	2
Subsurface injection	2	2	1-2	2	2	x	x	2	1	2	2
Fluid compatibility	2	2	2	2	2	x	x	3	2	2	2
Migration	2	2	2	2	2	x	x	2	1	2	2
Air quality	1-2	2	3	1	1			3	1	3	1
Land use	2	2	3	1	1			3	1	3	1
Solid waste	1	2	3	1	1			3	1	3	1
Occupational	1	2	2	2-3	1	x		3	1	3	1

Key to Environmental Assessment Matrix

Analogy
- 1-Direct
- 2-Partial
- 3-None

Information Base
- 1-Extensive
- 2-Moderate
- 3-None

Experience Level
- 1-High
- 2-Medium
- 3-Low

Research
- x-Research required
- blank-No research required

Magnitude
- 1-Major
- 2-Minor
- 3-Insignificant

Mitigation
- 1-Technology well developed
- 2-Technology partially developed
- 3-Technology poorly developed

Uncertainty
- 1-Major uncertainty about impacts
- 2-Medium uncertainty about impacts
- 3-Low uncertainty about impacts

Consensus
- 1-Major agreement among experts
- 2-Some areas of disagreement among experts
- 3-Wide range of expert opinion

n.a.-Not applicable
?-Uncertain
*-Strategic Petroleum Reserve

FORECASTING ENERGY DEMAND FOR HAWAII*

H. Ruderman and P. Leung†

INTRODUCTION

As part of the Hawaii Integrated Energy Assessment, we have developed a macroeconomic model of energy consumption in Hawaii. The Hawaii Energy Demand Forecasting Model (HEDFM) was designed to provide detailed forecasts of energy demand for the state's four counties. Demands for various types of energy were projected for each year until 2005 in Table 1. A summary of the forecasts made is given in Table 2. Combining the demand forecasts with supply scenarios furnished by other elements of the integrated assessment permits quantitative analyses of a range of possible energy futures for the state. In addition, the HEDFM provides empirical insights regarding the structure of energy demand in the state and its relationship to the local and world economies.

Work on developing the model was begun by the Hawaii Department of Planning and Economic Development (HDPED) during FY 1979. As a first step, HDPED compiled a data base of information on energy consumption and prices, as well as on economic and demographic variables. Using these data, they developed an initial version of the macroeconomic model. LBL's participation in this effort began toward the end of FY 1979.

ACCOMPLISHMENTS DURING FY 1980

The model and data base were transferred from HDPED to LBL early in FY 1980. We set up the model on the PDP 11/780 VAX computer system operated by the Computer Science and Applied Mathematics Department. This enabled us to take advantage of the interactive graphics capabilities of SEEDIS, the Socio-Economic Environmental Demographic Information System at LBL. An interface between the HEDFM and SEEDIS was written so that the demand forecasts could be displayed and plotted.

After the final version of the model was completed, we made five forecasts of energy demand under various assumptions of economic and demographic growth, energy prices, and conservation. The five cases were chosen to examine the sensitivity of the model to these assumptions and to provide a range of energy futures for the integrated assessment. Three of the futures were actually used in the assessment.

Table 1. Demand categories.

Residential Electricity Sales
Nonresidential Electricity Sales
Total Electricity Sales
Aviation Fuel Consumption
Diesel Fuel (Nonelectrical)
Residual Fuel (Nonelectrical)
Utility Gas Sales
Liquid Petroleum Gas (LPG)
Total Energy Consumption

Table 2. Regional dissaggregation for the HEDFM forecasts.

Regions for Forecasts
Honolulu County
Maui County
Hawaii County
Kaui County
State of Hawaii

Structure of the Model

The HEDFM forecasts energy use directly from explanatory demographic and economic variables. The model relates consumption in a given year to price, income, and the previous year's consumption. For most energy types, a set of log-linear equations is employed. The advantage of this form is that the coefficients of the explanatory variables provide estimates of the short- and long-run

* This work was supported by the Office of Conservation and Solar Energy and the Office of Resource Applications of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

† Hawaii Department of Planning and Economic Development.

elasticities. The demand equations for each energy type are estimated using ordinary least-squares fitting of consumption data for 1963 to 1977.

The model for each fuel was estimated using several combinations of explanatory variables. The results were examined to confirm that the coefficients were of the proper sign and were statistically significant. They were also examined with respect to their suitability for forecasting. The pooled cross section-time series models gave the best results for electricity, gasoline, and diesel consumption. For residual fuel and LPG, a simple growth model was used for forecasting. The model for aviation fuel uses visitor arrivals and passenger load factors as the explanatory variables.

Forecasts

We examined three scenarios for energy demand in Hawaii. They differed in the future price of energy and in the level of energy conservation assumed. All three are based on the state's most likely projection of population and personnel income[1] and they assumed that the federally mandated automobile mileage standards will be implemented. The first case is a baseline projection assuming a 3%/yr escalation in world oil price above the general inflation rate. The second case, called the high price case, is based on a 10%/yr increase in oil price. The third case we called the savings case. In it, we modified the baseline forecasts by incorporating improved electrical appliance efficiencies.

Energy consumption in Hawaii during FY 1977 amounted to 200 x 10^{12} Btu. Of this total, approximately one-third was electricity, one-third aviation fuel, and the remainder primarily gasoline and other fuels for transportation. More than 80% of the energy and nearly all of the aviation fuel is consumed on Oahu. Except for a small amount of bagasse and hydropower, the energy comes from imported petroleum. During 1977, petroleum imports amounted to about 40 million barrels.

According to the baseline forecast, energy consumption is expected to increase to 354 trillion Btu in 2005. Reductions in consumption due to higher prices case would bring this total down to 244 x 10^{12} Btu, whereas improved efficiencies would reduce demand to 311 x 10^{12} Btu. These results are shown in Figure 1. The average growth rate in the baseline forecast is about 2.1%/yr. The largest growth will occur from 1985 to 1995. The savings case shows a similar behavior. The high price case, on the other hand, shows a growth in energy consumption of about 1%/yr until 1995 and then no growth thereafter.

The forecasts for total electricity sales in the state are shown in Figure 2. The baseline case shows an increase from 5.8 x 10^9 kWh in 1977 to 14.3 x 10^9 kWh in 2005. Most of this growth will occur in nonresidential sales. Residential sales will increase only by one-third because the large long-term price elasticity coupled with the forecasted price increases dampens demand growth. Savings from improved appliance efficiencies could amount to 3.8 x 10^9 kWh in 2005. This represents

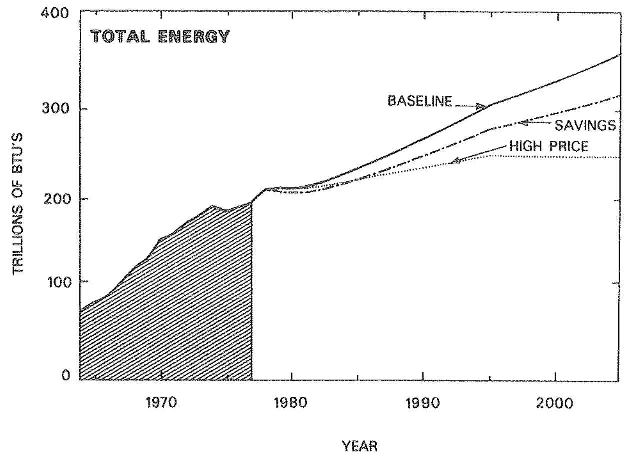

Fig. 1. Total energy consumption. (XBL 8012-2561)

a potential oil import reduction of about 7 x 10^6 bbl/yr. The high price case shows a leveling off and eventual decline in electricity consumption. By 2005, statewide consumption would be about 40% of the baseline forecast.

Our forecasts indicate that there will be a decline in the gasoline sales over the next twenty-five years. As shown in Figure 3, in the baseline and savings cases, gasoline sales will drop from 315 x 10^6 gal/yr to 155 x 10^6 gal/yr. Our results indicate that the currently mandated standards can reduce projected gasoline consumption by 60%. In the high price case, statewide sales in 2005 amount to 79 x 10^6 gal, about 75 x 10^6 below the baseline forecast or a quarter of the 1977 sales.

We made only one forecast for aviation fuel, using the state's projection that visitor arrivals would increase from 3.4 x 10^6 in 1977 to 8.2 x 10^6 in 2005, and we assumed that passenger load factors would gradually increase. Consumption nearly doubles during this period, reaching 860 x 10^6 gal by 2005.

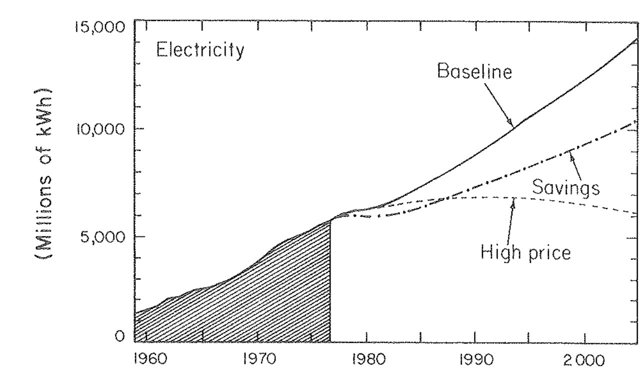

Fig. 2. Electricity sales. (XBL 8011-2338)

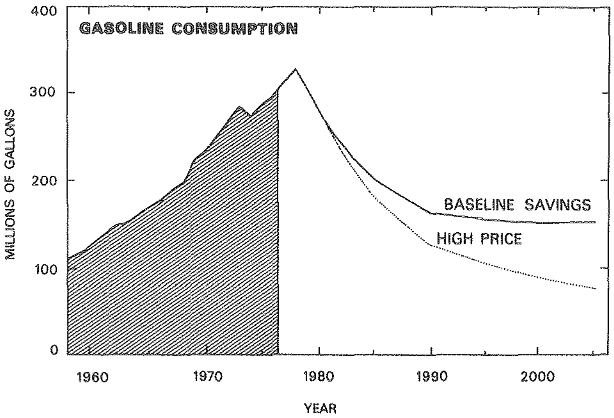

Fig. 3. Gasoline sales. (XBL 8012-2562)

The three demand forecasts described above do not take into account the impact of alternative energy technologies: The continuation of the current dependence on imported petroleum is assumed. Different energy supply scenarios will have different impacts on the economy in general which, in turn, will generate different energy demand patterns because of changes in the economic and demographic characteristics of the state.

PLANNED ACTIVITIES FOR FY 1981

Except for preparing a final report, work has been completed on the macroeconomic forecasting model. Towards the end of FY 1980, HDPED began gathering data and investigating methods for constructing an end-use model of energy demand in Hawaii. This type of model relates energy consumption to physical factors, such as the number of appliances in use and their unit energy consumption. End-use models tend to be more complex than macroeconomic models, and their data requirements are more extensive. However, an end-use model can provide better insight to the effects of policy decisions on energy consumption, because many of the factors that are affected by policy decisions can be incorporated in the model. During FY 1981 LBL will assist HDPED in constructing an end-use model of demand in the residential, commercial, and transportation sectors in Hawaii.

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FORECASTING THE ROLE OF RENEWABLES IN HAWAII*

J. Sathaye and H. Ruderman

INTRODUCTION

Having no fossil fuel resources of its own, the State of Hawaii is almost totally dependent on external sources of energy. More than 90% of the state's energy is imported in the form of crude oil or petroleum products. The rest comes from hydroelectric plants and from burning bagasse at sugar mills. Hawaii is therefore extremely vulnerable to disruptions in the world oil market. Determining the extent to which oil can be replaced is the major purpose of the Hawaii Integrated Energy Assessment, a joint study by the Hawaii Department of Planning and Economic Development (HDPED) and the Lawrence Berkeley Laboratory (LBL). A complete description of the study and discussion of the results will be found in a forthcoming multivolume report.[1]

Each of the four counties in the state appears to have enough resources, such as ocean thermal, wind, solar, and geothermal energy, to supply nearly all its energy needs. The question arises, "To what extent should each of these resources be developed during the next 25 years to provide the state with a reliable and economic energy system?" To examine the role of renewables in supplying energy, we have constructed an integrated energy supply-demand model for the state. Using this model, we have examined three energy futures for Hawaii under different assumptions about prices and energy conservation. These are summarized in Table 1.

In this summary of our work we describe the methods developed for assessing a variety of energy futures. As an example of our results, we present the electricity demand forecast, generation mix, and prices in Honolulu County for the first energy future.

ACCOMPLISHMENTS DURING FY 1980

Methodology

The methods and data developed during FY 1980 for determining energy futures for Hawaii and their impacts on the state's economy are summarized in Figure 1. The Hawaii Energy Demand Forecasting Model provided energy demand projections for each of the counties by year up to 2005. We made three

* This work was supported by the Office of Conservation and Solar Energy and the Office of Resource Applications of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

Table 1. Summary of Hawaii energy futures.

Future	Demographic Forecast*	World Oil Price Growth	Conservation
1.	"Most likely"	3%/yr.	Mandated automobile mileage standards.
2.	"Most likely"	10%/yr.	Mandated automobile mileage standards.
3.	"Most likely"	3%/yr.	Improved appliance efficiencies and mandated automobile mileage standards.

* From the Hawaii Macroeconomic Model Simulation, 1977. See Reference 2.

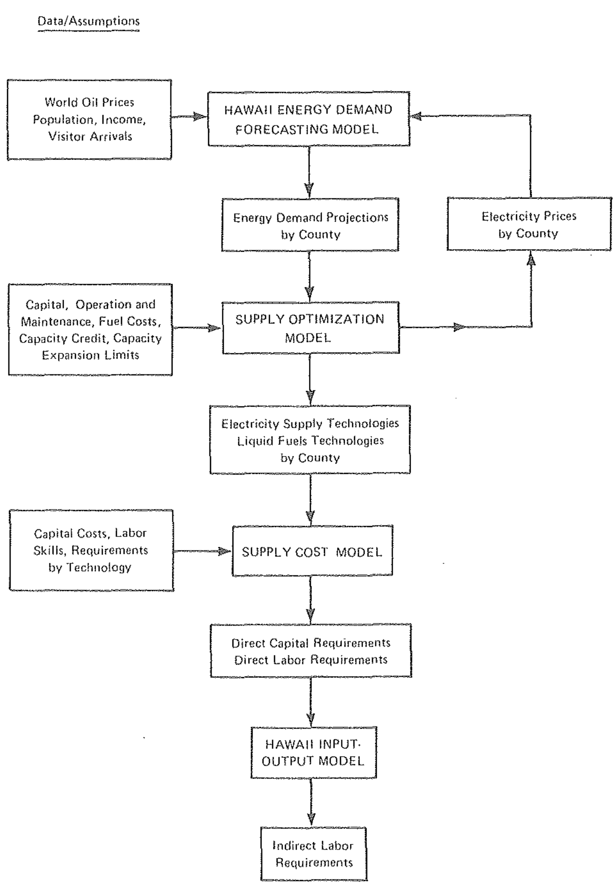

Fig. 1 Assessment methodology. (XBL 811-43)

forecasts which differed in their assumptions about energy prices and the level of energy conservation. The energy prices used in these forecasts are dependent on world oil prices. Demographic and economic projections were adopted from the state's forecasts.[2]

Because of the wide variety of technologies that will become available during the next 25 years, the projected electricity demands can be met in many ways. The technologies will differ in their costs, their reliability, their year of initial commercial availability, and in the amount of electricity they can ultimately supply. To facilitate the electricity supply-demand integration, the Supply Optimization Model was used to find the supply mix that meets the electricity demand and generating capacity demand at the lowest prices. In addition to determining the supply mix, the Supply Optimization Model also calculated the electricity prices for each county. In general, these prices were lower than those projected by the demand forecasting model. The new prices were fed back into the demand forecasting model, and a revised set of demand forecasts was obtained. We repeated this procedure until a consistent set of energy demands and prices was found.

The resulting supply scenarios were analysed for their direct and indirect economic impacts. Direct impacts include the materials, manpower, and equipment required to construct, operate, and maintain the new energy facilities. Indirect impacts include the income and employment in secondary industries within the state brought about by the expenditures on construction of the new facilities. We used the Supply Cost Model and our characterizations of renewable technologies to calculate the direct impacts in each county. The indirect impacts were estimated for the state as a whole using an input-output model of the state's economy.

Results

In this section we discuss our results for the County of Honolulu, of which Oahu Island is the principal part. Honolulu has about 80% of the state's population and accounts for more than 80% of its energy consumption. We present our projections of energy demand, the electricity generation mix, and electricity prices for the first future to illustrate the methods we developed to analyse the supply and demand options for the state. We are presently analysing the three supply-demand cases for the other counties. These results, along with the direct and indirect economic impacts in Honolulu County, will be published in Reference 1.

Energy Demand

Table 2 shows the energy demand on Oahu for the baseline case. The demand for electricity in Honolulu County will more than double during the next 25 years. Demand is heavily influenced by electricity prices, which will reach a plateau in 1955 as the fraction of electricity supplied by renewables becomes significant. Since electricity prices will no longer depend on ever-increasing oil prices, the demand for electricity will increase as prices decline or increase marginally.

The demand for imported petroleum will also reach a peak in 1995; then it will decline slightly in 2000 before increasing again in 2005. The non-electric portion of this demand will increase steadily; by 2005 it will be 40% higher than its present level. Oil required for electricity generation, however, will peak in 1990 and then decline to its lowest level by 2000. This decline is due to the rapid penetration of the renewables into the electricity supply mix after 1990. Although renewables will continue to increase their share after 2000, the use of oil will also increase because the maximum penetration by renewables is limited to a level insufficient to meet the increasing demand. Oil used for generation on Oahu will drop to 37% of renewables.

Supply Mix

Imported petroleum has been the predominant source of electricity in Hawaii for many years.

Table 2. Energy demand projections for Honolulu county baseline case with inter-island cable (trillions of Btu's).

	1980*	1985	1990	1995	2000	2005
Electricity						
Residual	57.1	60.9	65.3	54.6	23.2	37.8
Diesel	0.0	0.8	1.8	0.3	0.0	0.4
Oil total	57.1	61.7	67.1	54.9	23.2	38.2
Renewables at oil equivalent	1.4	4.5	9.9	38.8	91.2	104.1
Generation (10^6 KWh)	5,230	5,940	6,900	8,410	10,250	12,760
Liquid Fuels						
Gasoline†	25.7	17.8	14.0	13.2	12.6	12.5
Residual and diesel	18.9	21.3	24.2	27.6	30.9	34.7
LPG and utility gas	4.3	4.5	4.7	4.9	5.1	5.3
Subtotal	48.9	43.6	42.9	45.7	48.6	52.5
Aviation fuel	65.8	80.7	94.1	105.7	107.0	108.7
Total	114.7	124.3	137.0	151.4	155.6	161.2
Total oil demand	171.8	186.0	204.1	206.3	178.8	199.4
Oil demand without renewables	170.6	186.6	210.4	238.5	257.3	280.2
World oil price (1980 $/bbl)	30	35	40	47	54	63

* The figures for 1980 are estimates of demand, not actual consumption data.

† Alcohol could substitute for at least ten percent of gasoline consumption beyond 1990.

Bagasse combined with oil and hydropower have also contributed to the electricity supply, especially on the Neighbor Islands. Their contribution on Oahu has been relatively small. Figures 2 and 3 show the forecasts of generating capacity and the amount of electricity generated by each type of power plant for the next 25 years. The peak loads and reserve margins are indicated on the bars in Figure 3. The capacity demand includes a 20% reserve margin. We assumed that all the oil generating capacity available in 1980 will remain on line through 2005 to serve as a backup. The proposed 45 MWe of municipal solid waste (MSW) and 40 MWe of ocean thermal energy conversion (OTEC) plants have been included starting in 1985 and 1990, respectively. Additional generation from OTEC was included if it could compete favorably with the other technologies.

Oahu will continue to use its oil-fired power plants for baseload generation until about 1995. As OTEC and geothermal plants come on line for baseload, oil generation will mainly be used for intermediate and peaking loads. At the same time, wind and solar will also make major contributions. About 140 MWe of gas turbines will be built by 1990 to meet peaking loads. The largest capacity increments will occur between 1995 and 2000 when 830 MWe of new wind, solar thermal, OTEC, and geothermal plants will be constructed.

Electricity Prices

Electricity prices are related to the price of oil and to the cost of generating capacity. It is not surprising that, as the price of oil increases, so does the price of electricity. Electricity prices will increase rapidly until 1990. After this date, as lower-cost renewables become available, prices will decline or increase slightly. For Honolulu County, the average electricity price by 1990 will go from 86 mills/kWh to 109 mills/kWh, a 27% increase. During the subsequent 15 years, prices will increase by only 5%. The lower prices result in a larger demand than originally forecast assuming electricity would be generated primarily from oil.

PLANNED ACTIVITIES FOR FY 1981

During the first quarter of FY 1981, we will complete our analysis of the three energy futures for all four counties. We will examine some of the other options that are available to the state, such as the use of coal or biomass for generating electricity. The project should be completed during

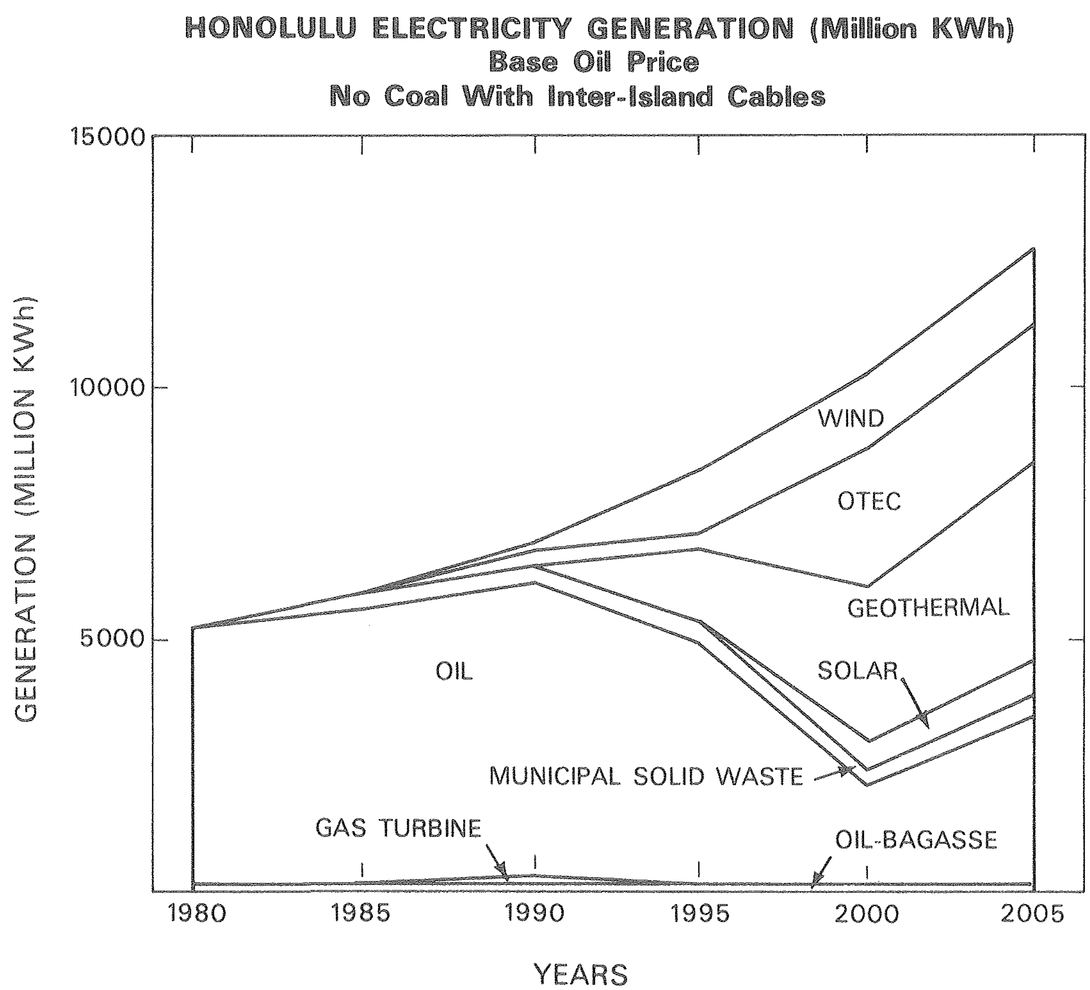

Fig. 2 Generating capacity in Honolulu County, Future 1. (XBL 8012-2557)

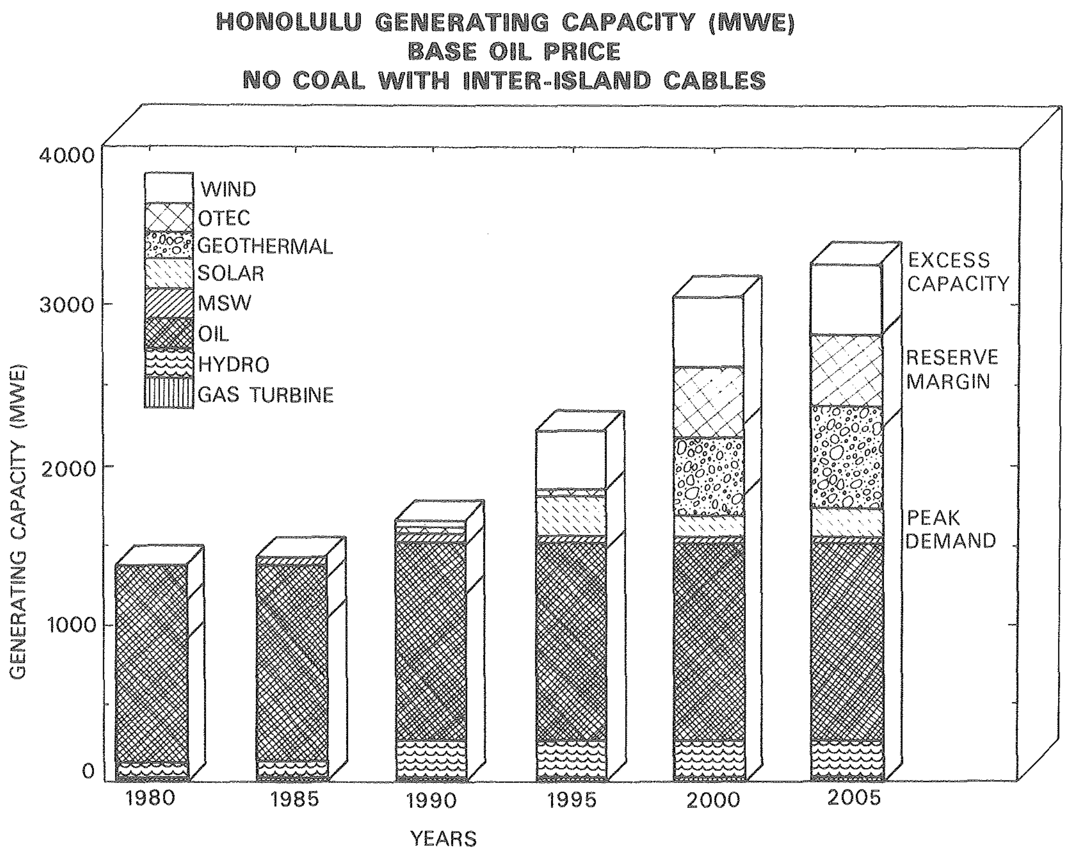

Fig. 3. Electricity generation in Honolulu County, Future 1. (XBL 8012-2559)

the second quarter with the publication of several volumes documenting our work.

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COASTAL ZONE ASSESSMENT PROGRAM*

R. Ritschard and K. Haven

INTRODUCTION

The coastal regions of the United States are rare, biologically important, and vulnerable to human perturbation. The coastal zone has been and will continue to be important in the nation's industrial development. The placement of energy facilities there generates environmental impacts and creates conflicts in the use of our coastal resources.

Since the coastal zone has been recognized by Congress and various coastal states as a geographic region of special concern, a set of state and federal institutions have been created specifically for coastal zone management. Other governmental regulatory agencies at the federal, state, and local level have been given topically specific authority for their coastal zone activities. While the number of agencies involved in

* This work was supported by the Regional Impacts Division, Office of Environmental Impacts, U.S. Department of Energy under contract No. W-7405-ENG-48.

the management and regulation of the coastal zone is vast, the involvement of each tends to have a single purpose. With the exception of outer continental shelf (OCS) oil and gas development, which is regulated by the Bureau of Land Management, U.S. Department of the Interior, energy development in the coastal zone is not the primary concern of any agency. Furthermore, these agencies tend to be regulators rather than planners; they have limited geographic jurisdictions; and they usually evaluate projects on a site-by-site basis.

Coastal energy activities are of great importance in the Pacific Coast region (Alaska, California, Hawaii, Oregon, and Washington). Nearly 90% of the region's electrical generating capacity (excluding hydroelectric), more than 50% of all regional oil production, and more than 80% of the region's refining capacity is located in the coastal zone. To date, the impacts of coastal facilities and activities have been evaluated on a site-specific basis, yet energy facilities in the coastal zone serve and affect an area far beyond the site. It is therefore imperative that the assessment of coastal energy development be conducted from a regional perspective and in an integrated fashion.

The Coastal Zone Assessment Program was initiated during FY 1980 to conduct integrated assessments of environmental, socioeconomic, and institutional impacts on the Pacific coastal zone as the result of energy development. The program emphasizes the cumulative effects of key energy and environmental impacts, identified and characterized by type and geographic area.

ACCOMPLISHMENTS DURING FY 1980

During FY 1980, the Energy Analysis Group at LBL, in conjunction with the Brookhaven National Laboratory, initiated a coastal zone assessment program. LBL's responsibility included the Pacific coastal region (Alaska, California, Hawaii, Oregon, and Washington).

The coastal zone has been recognized by Congress and by the various coastal states as having special significance to the economic and environmental well-being of the nation. Yet, there is no coastal-specific energy policy that considers both the development and implementation of a strong energy program and the attainment of the nation's environmental protection goals.

During the first year, the present and projected energy-related activities in the Pacific coastal region were addressed within the context of existing federal and state coastal management programs. Several regional energy supply issues in the coastal zone were identified: concentrated and dispersed facility siting; conversion to coal-fired power plants; OCS development; petroleum supply systems; siting of new technologies; and the cumulative impacts of energy activity.

The decision-making framework that has been created at the state and federal levels to protect the economic and environmental value of coastal resources was characterized. The major federal legislation is the Coastal Zone Management Act (1972) and its 1976 amendments. This act established the federal program that encourages the states to develop a planning process for coastal zone-related energy activities. Since state and local agencies are responsible for coastal planning, for implementing energy development in the coastal zone, and for bearing the environmental and socioeconomic impacts inherent in a particular energy activity, these agencies must be considered when federal energy plans are proposed.

An analysis of the interrelationships between federal, state, and local energy interests in the coastal zone indicated that two major roles are available to DOE's Office of Environment. The two roles are: (1) the analysis of the environmental impacts of various energy technologies and of proposed policies; and (2) the transfer of information from federal to regional, state, and local agencies that are responsible for coastal energy planning.

Within the first category, several new functions are proposed, including the identification of specific energy technologies and programs that may cause environmental impacts; and the integrative assessment of all energy-related activities within a large geographic area of the coastal zone, e.g., the Pacific Coast. The process of information transfer comprises the following proposed tasks: determine the regional, state, and local implications of federal energy supply scenarios; establish liaison with state and local agencies in order to define and clarify "national interest"; and act as a clearinghouse for energy and environmental data pertinent to the coastal zone.

The success of a well-coordinated national energy program that deals with the development of coastal energy resources while protecting the coastal environment will require better coordination between the federal, state, and local agencies involved. The authors feel that the Assistant Secretary for the Environment can play a critical part in this effort.

PLANNED ACTIVITIES FOR FY 1981

Several tasks are planned for FY 1981 in order to develop and apply a coastal assessment methodology to the Pacific Coast region. These activities include:

- Conduct of a regional coastal characterization that includes a detailed quantitative description of each component of the coastal energy technologies as they will be applied along the West Coast; identification of the most vulnerable estuarine systems; and selection of plausible siting patterns. Table 1 outlines the offshore and onshore requirements of various energy supply activities.
- Application of the coastal screening system to an appropriate scenario in order to establish residual loading patterns and to identify key coastal impact areas.

Table 1. Dependence of energy supply technologies on the coastal zone.

Energy Supply Activity	Offshore Requirements	Onshore Requirements
Offshore oil/gas production (pipeline)	Platform sites Gas treatment plant Pipeline to shore (oil and gas)	Platform fabrication yard Pipeline terminal and pumping plant Storage facilities Port support facility
Offshore oil/gas production (tanker)	Platform site Tanker loading bouy site On-site oil storage Gas treatment plant Gas pipeline to shore Tanker traffic lanes	Platform fabrication yard Tanker terminal Port storage facility Port support facility
Onshore oil/gas production		Well sites Pipelines Storage facility
Oil/gas processing	Tanker traffic lanes Barge traffic lanes Offshore terminals/ lightering sites	Pipelines Refinery Storage facilities Crude/product tanker terminals Product barge terminals
Liquefied natural gas	Offshore terminal (if selected over onshore terminal) Pipeline to shore Tanker traffic lanes	Regasification plant Tanker terminal Pipeline interties Storage facilities
Electric power plants	Tanker/barge lanes for waterborne fuel delivery and water-borne waste removal	Plant site Fuel delivery (waterborne); tanker/barge terminals Fuel delivery (rail); rail routes and terminals Fuel delivery (pipe); pipelines Onsite fuel storage Transmission lines Ash removal/disposal system
New technologies		
OTEC	Plant site Transission line	Platform fabrication yard Port support facility Cable intertie
Marine biomass	Farm site Harvest ship transit routes	Port support facility Farm fabrication plant Terminal for harvest ship Conversion plant Pipelines for gas supply
Wave energy	Plant site Maintenance ship travel Cable to shore	Fabrication plant Support base
Wind energy		Coastal plant sites Transmission lines

- Conduct of a detailed assessment of the environmental, socioeconomic, and institutional impacts resulting from the scenario's coastal energy activity and associated water quality impacts.

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1. R. Ritschard, K. Haven, and J. Cherniss, Energy in the Pacific Coastal Zone: Does D.O.E. Have a Role? Lawrence Berkeley Laboratory report LBL-11154, 1980.

A SUMMARY OF REGIONAL IMPACTS ASSOCIATED WITH THE SECOND NATIONAL ENERGY PLAN*†

R. Sextro, V. Berg, T. Chapman, M. El-Gasseir, P. Podvin, H. Ruderman, J. Sathaye, S. Schaffer, and K. Tsao

INTRODUCTION

The analysis of various national energy scenarios for potential regional environmental, socioeconomic, and institutional issues has been a continuing program within the Energy Analysis Program. Typically these assessments have had as a major objective the early identification of major impacts posed by national energy policies or strategies. This identification and assessment process is conducted at the state and local levels within each federal region, and therefore provides a "bottom-up" policy perspective for the U.S. Department of Energy.

This article summarizes the results of the Regional Issue Identification and Assessment project at LBL, which was based on an analysis of the President's Second National Energy Plan (NEP-II).[1] This project was conducted for the Regional Impacts Division, Office of Environmental Assessments of the Assistant Secretary for Environment, U.S. Department of Energy (DOE).

ACCOMPLISHMENTS DURING FY 1980

Scenario Discussion

The major assumptions of the scenarios based on the National Energy Plan are:

- Replacement cost pricing is achieved through gas and oil price deregulation;
- Increased coal use occurs with no federal coal-leasing barriers, and with federal policies designed to limit oil and natural gas use in utility and industrial boilers;
- Tax incentives are passed for new technologies, such as solar and oil shale, with these sources contributing 8 quads/yr and 2.5 quads/yr respectively by 2000;
- Nuclear power continues to be utilized, producing 17 quads/yr by 2000 (330 GW of installed capacity);
- GNP growth averages 3.5%/yr to 1985, then 2.9%/yr from 1985 to 2000;
- World oil prices move to $30/bbl by 1990, and $38/bbl by 2000 in the high oil price trajectory, and $17/bbl by 1990 and $21/bbl by 2000 in the low oil price case (1979 dollars).

This study focused primarily on the high world oil price scenario; the scenario based on low world oil prices was examined only where significant differences existed between the scenarios. Nationally, energy supply is expected to grow at almost 2%/yr. Overall reliance on natural gas and oil is projected to decrease slightly by the end of the century, while coal and nuclear are both expected to increase substantially during the same period. Alternative energy sources, particularly solar and geothermal, are expected to make a small contribution to the energy supply by 2000.

These national energy scenarios were disaggregated into regional supply and demand values for each of the ten federal regions. The scenario derived from the high world oil price case is shown in Table 1 for Federal Region IX. At the regional level, the overall growth rate in primary energy use is 1.5%/yr annually between 1975 and 2000. Aggregate natural gas use declines slightly, while oil use increases somewhat during this period. Coal use, however, increases dramatically as an industrial and utility boiler fuel, growing at nearly 7.5%/yr. Nevertheless, per capita energy use in the region is projected to decline during the last quarter of this century.

The increased emphasis on offshore oil and gas production is the most significant change in fossil fuel supply in the region. Imports of these two fuels increase somewhat to the middle of the time period, then decline to about the same level as the 1975 imports. Most of the increased coal use in Region IX is met by imports from other parts of the West as Region IX coal production expands only slightly.

The most substantial changes occur in the electricity sector, where sales are projected to increase by 3.5%/yr. Fuel use for electricity generation is shown in Table 2. The two sources with the largest changes are nuclear and geothermal, both growing by 10%/yr.

No major changes in technologies have been assumed in this study. New energy technologies, such as photovoltaics, fusion, the breeder or fluidized-bed combustion, have not been explicitly considered in the scenario. A regional siting pattern for supply and conversion facilities was assembled, based on utility, industry, or state agency plans in order to facilitate the assessment of impacts and issues arising from the scenario.

* This work was supported by the Office of Environmental Assessments, Assistant Secretary for Environment, U.S. Department of Energy under contract No. W-7405-ENG-48.

† Condensed from Lawrence Berkeley Laboratory report LBL-12024.

Table 1. Energy supply and use for Region IX based on NEP-2 (high world oil prices). (10^{12} Btu/year)

	1975[a]	1985	1990	2000
Regional production				
Coal	157	168	229	240
Crude oil	1870	2789	2815	2122
onshore	1413	2207	2026	1406
offshore	462	582	788	716
Natural gas	389	624	575	532
onshore	358	357	313	329
offshore	31	267	262	203
Hydro (electricity)[b]	490	496	550	550
Geothermal (electricity)[b]	33	181	295	421
Solar (electricity)[b]	0	0	5	150
Total regional supply	2939	4258	4469	4015
Fuel imports to Region IX				
Coal	34	273	544	1004
Oil	1400	1380	1231	1476
Natural gas	1689	1170	1261	1415
Nuclear (fuel)	64	363	598	1051
Total imports	3187	3186	3634	4940
Total supply	6126	7444	8103	8961
Regional energy consumption				
By end-use fuel type				
Coal	9	51	213	391
Oil	2638	2586	2466	2222
Natural gas	1750	1747	1798	1933
Electricity	601	871	1092	1433
Total	4998	5255	5569	5979
By end-use sector				
Residential	926	889	1000	1237
Commercial	576	576	605	682
Industrial	1146	1557	1790	1906
Transportation	2350	2235	2174	2154
Total	4998	5257	5570	5979

[a]Federal Energy Data System, 1975.

[b]10,000 Btu/kWh.

Assessment Results

The scenario analysis was undertaken in two basic ways. Key issues that are critical to the regional implementation of the National Energy Plan were assessed. In addition, an analysis of the potential impacts was conducted. This section summarizes the study results for the Key Regional Issues. Detailed reports summarizing the air quality, water resource, ecology, and land use analyses are presented in companion articles in this annual report.

Key Regional Issues

Oil and Natural Gas Development

The scenario projects an increasing level of oil and natural gas production from Region IX sources, all of which would come from onshore and offshore California. With the exception of those areas with enhanced oil recovery (EOR) operations, production from existing onshore oil and gas fields is declining. Some of the areas with large EOR activity do not meet ambient air quality standards

Table 2. Fuel use for electricity production in Region IX (high world oil prices). (10^{12} Btu/year)

Fuel	1975[a]	1985	1990	2000
Coal	182	389	560	853
Oil	632	1583[c]	1580[c]	1376[c]
Gas	328	46	38	15
Nuclear	64	363	598	1051
Hydro[b]	490	496	550	550
Geothermal[b]	32	181	295	421
Solar[b]	0	0	5	150
Total	1728	3058	3626	4416

[a]Federal Energy Data System, 1975
[b]10,000 Btu/kWh.
[c]Includes some combined cycle plants.

for sulfur oxides. Hence, significant expansion of EOR operations in these areas will require the use of better emission controls.

Increased offshore oil and gas activity has considerable state and local opposition. One of the major issues is whether current outer continental shelf leasing plans are consistent with provisions of the federal Coastal Zone Management Act. The State of California also claims that the environmental review for the new leasing programs has been inadequate. Oil and gas development offshore will probably encounter a number of constraints; therefore the scenario projections regarding these resources may be optimistic.

Increased Coal Use

As can be noted from Tables 1 and 2, coal use is expected to increase rapidly in Region IX. In the industrial sector, much of this increase would take place in the industrialized metropolitan areas, most of which are nonattainment areas for one or more pollutants. At the same time, regional emissions from increased coal burning in this sector are estimated to increase 16 times for particulates and nearly 40 times for sulfur oxides. Required emission tradeoffs may therefore be difficult to obtain. In addition, the coal-handling infrastructure has not been developed in metropolitan areas of Region IX, unlike other industrialized areas of the country where industrial coal use has been established.

A number of new coal-fired power plants are projected by the scenario for the region. These plants should meet the federal New Source Performance Standards that have been adopted for most areas of the region. Many of the likely sites for these facilities are expected to be in rural or semirural areas where population impacts are reduced. However, in some cases the local area is in the nonattainment category; hence, emission offsets would still be required before the plant could be permitted. Most nonattainment areas do not have large local emission sources that can be used as tradeoffs for the proposed power plant.

Some states are considering the use of tighter controls on nitrogen oxide emissions. While this may increase plant costs, the lower resulting emissions may make finding emission offsets less difficult and it may reduce environmental impacts.

Nuclear Power

The scenario projects a nearly 13-fold increase in nuclear power by 2000. However, several states in the region have adopted legislation restricting development of new nuclear power plants until concerns regarding waste disposal, plant reliability, and overall emergency planning have been addressed. Similarly, public utility commissions throughout the region have expressed skepticism about utility financing of major capital intensive projects such as nuclear power plants. Costs for new nuclear plants have escalated considerably in the past several years.

In addition, the federal regulatory uncertainty following the accident at Three Mile Island has intensified state concerns. Emergency planning has become a major issue at plants currently in operation or under construction in the region. For all these reasons, the projected level of nuclear power development in the region is not likely to be attained.

Rural Development Impacts

Some energy developments proposed for Region IX will be located in rural areas because of the energy resource's location, as in the case of coal or geothermal energy deposits, some solar technologies, and onshore facilities needed for offshore oil and gas production. Other projects, such as coal or nuclear power plants, utilize rural sites as a means of reducing population impacts or risks. Changes in population and the resulting increase in demand for community services due to construction and operation of energy facilities are one of the main indicators of socioeconomic impact.

The extent to which communities are able to assimilate these changes depends on state and local tax laws, and on local economic conditions. Some communities in Region IX see energy development projects as a way of aiding the local economy and have encouraged such projects. In other cases, particularly following the passage of tax or local spending limitations, such as Propositions 13 and 4 in California, communities may not be able to raise or spend monies to cope with these impacts. Thus local socioeconomic impacts have become, and are likely to remain, important elements in the siting decision process, especially with regard to planning and implementing mitigation measures.

Financing Energy Development

Increasing marginal prices for new energy supplies and high interest and inflation rates have combined to make equity financing of new energy projects difficult and expensive for electrical utilities. The ratio of market price to book value of utilities' common stock has declined in the past few years. At the same time, the capital intensity of the utility industry has increased. An accelerating construction and concomitant financing program will be required in order to meet the projected doubling of the region's electrical generating capacity. Since 80% of Region IX's electricity demand occurs in California, the utilities in that state will bear much of the financial burden of regional electrical energy expansion.

The ability to fund new projects will hinge on a number of factors, including rate regulation policies and the condition of external capital markets. Changes in utility rates generally have not kept pace with rapidly increasing costs, and concerns over fuel and technology choices and over environmental issues have become increasingly important in the regulatory process.

Overall, project financing is likely to be one of the major constraints to implementation of the NEP-II scenario. Several regional coal projects currently in the regulatory process have been delayed since traditional means of utility financing are apparently not capable of providing capital for simultaneous major projects.

PLANNED ACTIVITIES FOR FY 1981

A study of a larger number of western states has been initiated in cooperation with Los Alamos Scientific Laboratory. This study will develop a set of scenarios describing future energy, economic, and demographic growth in the region, and will provide an assessment of the environmental consequences.

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EVALUATING LAND USE AND ECOLOGICAL ISSUES ASSOCIATED WITH FUTURE ENERGY PROJECTIONS*

V. Berg

INTRODUCTION

Energy production and conversion require the use of land, often displacing an existing land use. Energy activities can also indirectly affect the use of larger areas of nearby land. Similarly, energy resource development can affect natural ecosystems either directly, through habitat disruption, or indirectly, as a result of residuals released into the environment.

Many of the residents of Federal Region IX have expressed concern about the possible land use implications and ecosystem disruption associated with energy development. This research is an assessment of some of the potential interactions between energy development patterns, land use, and natural ecosystems.

ACCOMPLISHMENTS DURING FY 1980

This report summarizes a study performed as part of the Regional Issues Identification and Assessment (RIIA) project, which is described elsewhere in this report.[1] The assessment was based on two oil price scenarios that were developed as part of the President's second National Energy Plan (NEP-II).

Direct Land Use

Table 1 lists the estimated land areas in Region IX directly affected by the energy activities in the NEP-II High World Oil Price scenario. The two types of electrical generation facilities with the largest capacity in the scenarios are nuclear and coal-fired power plants. These power sources occupy about 350 and 1200 acres per site, respectively. On a per-megawatt basis, direct land use for these power plants is among the lowest of the generation facilities studied.

Oil, combined cycle, and natural gas-fired power plants also occupy a relatively small area. Due to rising petroleum prices and policy decisions, no new facilities of these types are projected in the NEP-II scenario after 1986.

Geothermal, solar thermal electric conversion, and wind turbines require a large area of land per megawatt of capacity due to the dispersed nature of their energy sources. Not all the land area in their collecting fields is physically occupied by the facilities, but the entire land area was included in Table 1 because energy collection and conversion is the dominant land use in those areas.

The biomass facilities in the scenario were assumed to be fueled by municipal solid waste (MSW) and to be located in urban areas. They are the only energy technology in the scenario that is expected to result in a net decrease in land area used. This curious result occurs because the burning of MSW reduces the need for sanitary landfills, and this more than compensates for the land area physically occupied by the plant. The number of new residents expected in each county under the

* This work was supported by the Regional Impacts Division, Office of the Environment, U.S. Department of Energy under Contract No. W-7405-ENG-48.

Table 1. Land area needed for energy development under the RIIA High World Oil Price Scenario, 1976-2000. (Acres)

Technology	Ariz.	Calif.	Hawaii	Nev.	Total
Nuclear	386	2,180	0	0	2,566
Coal	6,960	5,330	0	3,655	15,945
Oil and combined cycle	102	947	157	0	1,206
Natural gas	0	0	0	0	0
Geothermal	0	25,574	1,786	7,824	35,184
Hydroelectric	1,230	7,906	0	0	9,136
Biomass (MSW)	0	-3,107	0	0	-3,107
Solar thermal	5,029	9,387	0	335	14,751
Wind	411	19,880	0	411	20,702
Subtotal	14,118	68,097	1,943	12,225	96,383
Surface mining	9,362	0	0	0	9,362
New residents (number)	2,430	10,779	0	19,460	32,669
New residents (acres)	307	1,362	0	2,460	4,129
Total acres	23,787	69,459	1,943	14,685	109,874

scenario was calculated by Argonne National Laboratory using the Social and Economic Assessment Model (SEAM).[2] These results were used to estimate the land area needed for homes, schools, water supply, etc.

Habitat Disruption

Table 1 shows a total of 109,874 acres directly affected by new energy facilities in Region IX. Much of this land use will displace native plants and animals from their habitats. In some cases, e.g., geothermal development, the most significant effect has been the physical removal of vegetation in the course of facility and road construction.

The hydroelectric development projects in the RIIA scenarios will probably change aquatic temperature regimes, oxygen content, water flow and siltation patterns, and salinity. These changes, in turn, may affect aquatic organisms at the reservoir site and for many miles downstream.

Threatened and Endangered Species

The problem of habitat destruction is especially critical for endangered species, whose habitat requirements are often extremely specific. Data on the number of endangered species in each county[3] were used to assess the relative constraints to facility siting in different counties. These data were adjusted statistically to eliminate bias due to the sizes of the counties.

California's coastal counties have more than their share of endangered species due to diverse topography; to a large number of native species; and to major climate changes during recent geologic history. The arid counties of Southern California have many endangered aquatic species, mostly limited to small areas with adequate water. Finally, urban counties contain more endangered species, possibly due to past conflicts with people or because rare species are more easily noticed and studied in those counties.

Indirect Effects on Nearby Land Uses

Most electrical generation technologies have some effects on land uses outside the power plant boundaries. The most striking example of this is nuclear power. Despite the safety assurances of nuclear power proponents, many members of the public believe nuclear power poses unacceptable risks.[4] This affects the desirability of some land uses for many miles around.

Because power sources such as geothermal and wind must be sited in the limited geographic area where they occur, conflicts with other land uses usually cannot be avoided by changing the development site. Geothermal operations at The Geysers in Northern California have already conflicted with the quiet, rural lifestyle cherished by many local residents. Many potentially valuable wind resource areas cannot be developed because they are located on federal land with wilderness attributes.

The major off-site effect of coal use on other land and resource values results from visibility degradation in recreation areas. A third of the National Park managers in Region IX believe that visibility impairment is damaging to the parks' resources.[5] Visibility problems reduce the recreation experience of most park visitors, thus diminishing the value of an important western resource.

Air Pollutant Effects on Vegetation

Of all energy impacts on ecosystems, air pollutants may affect the widest geographic area. In Region IX in 1975, about 80% of the SO_2 emissions were produced by poorly-controlled nonferrous smelters. By the year 2000, the smelters are expected to greatly reduce their emissions. However, the NEP-II projection of a fourfold increase in utility and industrial coal and oil fuel use would leave SO_2 emissions in 2000 at about the same level as in 1975.

SO_2 damage to crops is expected to continue in the same areas as in 1975 (Fig. 1). The four counties in southeastern Arizona are affected under both the High and Low World Oil Price scenarios. The urban counties in California are only affected under the Low World Oil Price scenario. SO_2 damage to natural vegetation (Fig. 2) follows a similar pattern as for SO_2 damage to crops.

Figures 1 and 2 refer only to levels of SO_2 high enough to cause acute visible symptoms of injury. Synergistic effects with other pollutants and chronic low-level injury patterns may be more widespread and significant, especially in natural communities where competition plays an important role.

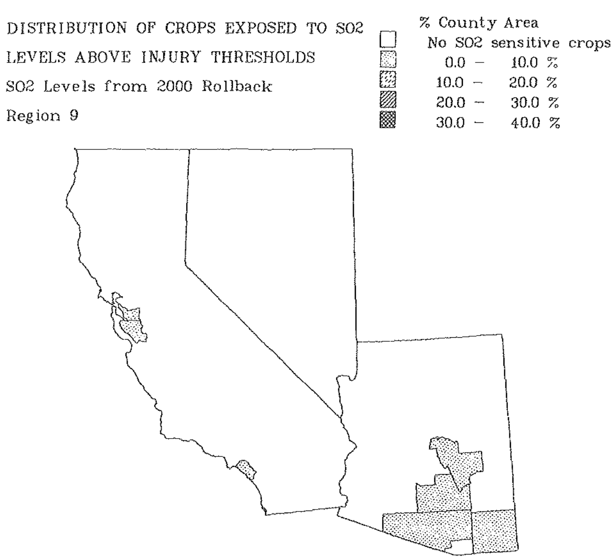

Fig. 1. Distribution of crops exposed to SO_2 levels above injury thresholds. NEP-II Low World Oil Price Scenario. (XBL 8011-3905)

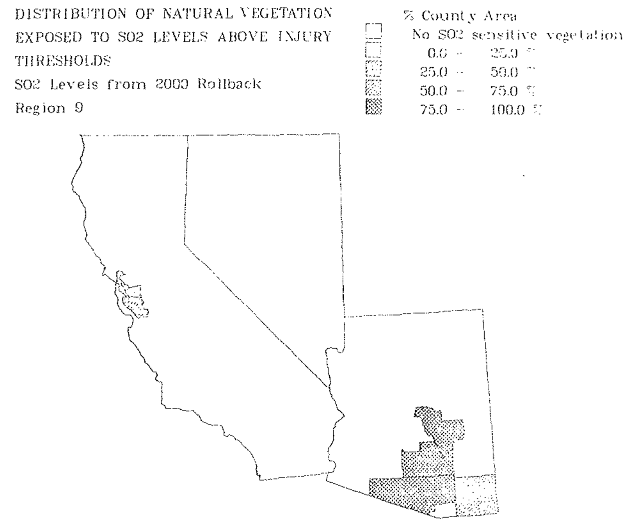

Fig. 2. Distribution of natural vegetation exposed to SO_2 levels above injury thresholds. NEP-II Low World Oil Price Scenario. (XBL 8011-3904)

Acid Rain

Acid precipitation has not been as extensively studied in Region IX as in some other areas, but it is receiving increased attention. The acidity of rainfall here is apparently increasing, and has been measured at values as acidic as pH 4.

The mountainous regions of the West tend to have shallow soils with low buffering capacity, so the full impact of acid deposition may be felt by aquatic organisms.

The desert areas of the West may not be severely affected by acid rain because the surface layer of many desert soils contains limestone, a good buffer. Where the soil surface is disturbed, as in surface mining, effects on aquatic ecosystems may be increased. This could be significant to the endangered aquatic species of the desert areas.[6]

PLANNED ACTIVITIES FOR FY 1981

A study of a larger number of western states has been initiated in cooperation with Los Alamos National Laboratory. This study will develop a set of scenarios describing future energy, economic, and demographic growth in the region, and will provide an assessment of the land use and ecological consequences.

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AIR QUALITY CONSTRAINTS ON IMPLEMENTING THE NATIONAL ENERGY PLAN IN FEDERAL REGION IX *

T. Chapman and R. Sextro

INTRODUCTION

This analysis is based in part on the changes in emissions of fine particulate matter (FPM) and sulfur oxides (SO_x) in Federal Region IX that would result from implementation of the National Energy Plan (NEP-II). While pointing out some assumptions to which outcomes are sensitive, the findings presented here should help elucidate the major constraints to the plan's achievement. This discussion focuses primarily on the high world oil price case (HWOP) for the NEP-II. Where significant differences arise, the assessment results from the low world oil price (LWOP) scenario will be included.

Air quality in Region IX ranges from pristine to highly polluted, and as a result of public awareness of the resource, vigorous local interests have long made air pollution control a primary political issue. Although basic research and enforcement are well-funded, most of the urban areas in this region, as in others, are nonattainment areas for one or more pollutants, usually oxidants.

New emissions sources in many of these areas will require emissions offsets if the new sources are to be permitted at all. At the other extreme, Region IX has 44 mandatory Prevention of Significant Deterioriation (PSD) Class I areas, and a number of additional areas under review for Class I status. Thus, siting in rural attainment areas may also be constrained by Class I concentration limits and/or visibility rules.

* This work was supported by the Regional Impacts Division, Office of the Environment, U.S. Department of Energy under Contract No. W-7405-ENG-48.

MAJOR FINDINGS

Particulates

Of total particulates, the FPM fraction has become the subject of closer scrutiny because of its potential for long-range transport (LRT) and visibility impairment, high respirability, and high chemical reactivity for these elements and compounds which are preferentially distributed in fly ash, and because of the greater difficulty in controlling its emission.[1]

The data aggregated in Table 1 for the region show an overall 27% increase in emissions from all sources between 1975 and 2000, and almost all areas in the region are predicted to experience degradation of air quality due to increases in fine particulate concentrations. Note that these data are for primary fine particulates (PFP) as opposed to sulfates, nitrates, and organic aerosols, which are secondary pollutants formed in atmospheric reactions.

FPM from industrial coal fuel-burning operations will increase by a factor of 15 while utility coal emissions increase tenfold. However, industrial and utility coal use together will account for only about 7% of total PFP emissions in the year 2000. At the same time some reductions in industrial process emissions are expected.

In spite of the activity in the utility and industrial sectors, it is the increased contribution from mobile sources that outweighs all others--apparently an artifact from assumed high diesel fuel market penetration. A gain of 65% over 1975 levels puts the transportation sector at 53% of the total emissions inventory by the year 2000. The increase in this sector alone could account for the 27% increase overall, and it is almost twice the increment from all fuel use in the utility sector.

Comparing the two scenarios, the emissions in the high world oil price case are predicted to

Table 1. Fine particulate emissions[a] in Region IX. (10^3 tons per year)

Sector	1975	1990		2000	
		HWOP[b]	LWOP[c]	HWOP	LWOP
Utility - coal	2.2	21.1	21.1	23.6	22.8
Utility - oil	13.7	38.2	37.0	30.5	25.7
Utility - gas and solar	0.2	0.6	0.5	1.3	1.3
Industry - coal	0.04	0.5	0.7	0.7	0.7
Industry - oil	5.7	14.2	26.7	1.9	40.0
Industry - gas	2.4	3.9	3.5	4.0	3.5
Residential/commercial - coal	0.0	0.0	0.0	0.0	0.0
Residential/commercial - oil	4.7	2.0	2.7	1.6	2.5
Residential/commercial - gas	5.6	4.9	4.9	5.9	5.8
Fuels - extraction, processes and distribution	36.2	34.3	37.1	25.8	35.4
Transportation	111.8	129.4	131.0	183.9	185.8
Industrial processes (SIC-32)	45.4	24.8	24.8	31.1	31.6
Industrial processes - other	46.7	34.0	34.5	38.1	39.1
Other	3.0	1.8	1.8	1.8	1.9
Total	277.7	309.7	326.3	350.1	395.6

[a] These data were derived by assuming a fixed ratio of fine to total particulates for a given source category. Fines are, by convention, particles of less than 2-3 microns in diameter.

[b] HWOP denotes high world oil price scenario.

[c] LWOP denotes low world oil price scenario.

be only 88% of those in the low world oil price scenario, primarily due to a net 67% reduction in industrial oil burning by 2000 under the former, as opposed to a 700% increase in that sector under the latter scenario.

Sulfur Oxides

SO_x problems in Region IX are highly localized when compared to other regions. The existing violations in Kern County, for example, result from insufficiently controlled emissions from enhanced oil recovery (EOR) operations there.[2] However, the major source of SO_x emissions in this region is nonferrous smelting in Arizona.[3]

In 1975, Greenlee County in Arizona experienced more than 100 days in violation of the SO_2 National Air Quality Standards (NAAQS) due to smelters upwind.[4] As indicated in Table 2, these sources are expected to be largely controlled by the end of the century; hence the predicted 75% decrease in emissions from these smelters drives the overall Regional SO_x emissions inventory down by 40%.

The decline in smelter emissions tends to mask significant upward trends in other sectors, including an 80% increase from utility oil burning, which at 21% of the total is the second largest sector by the year 2000. SO_x from mobile sources increase by 160%, or by a factor of 2.6 (again probably due to the assumption of very high diesel penetration,) but the increase fails to keep pace with utility coal-burning emissions that rise by a factor of 3.6. Industrial coal sulfur emissions are predicted to rise from a negligible amount in the base year to almost 10% of the total by 2000 under the HWOP scenario.

Utility Sector

Most states have adopted the federal New Source Performance Standards (NSPS) prescribed by the U.S. Environmental Protection Agency (EPA). With the exception of California, these rules typically apply uniformly throughout a state because local Air Pollution Control District's APCD's, although having primary responsibility for control of stationary sources, have not elected to promulgate tighter standards. Urban districts in Arizona (Phoenix and Tucson) and Nevada, (Las Vegas and Reno) and some special problem areas, e.g., Yuma and Pinal-Gila, Arizona also have more stringent emissions regulations which apply to utility plants.

In California, most APCD's have elected to set their own emissions standards; and some are only half to a third the level of federal NSPS. However, certain areas are being urged to relax the more stringent regulations, e.g., mass emission limits ("Rule 67" type), and process weight-based standards.[5] There are also fuel sulfur content rules which, in order to permit burning of coal or crude oil, must be eliminated or reworked so that tighter emission controls are seen as equivalent to prescribing low sulfur fuels.[6]

Table 2. SO_2 Emissions in Region IX. (10^3 tons per year)

Sector	1975	1990		2000	
		HWOP[a]	LWOP[b]	HWOP	LWOP
Utility - coal	42.6	125.9	125.9	155.1	145.4
Utility - oil	171.7	389.7	377.2	307.5	256.2
Utility - gas and solar	0.2	0.5	0.5	9.5	7.9
Industry - coal	3.4	81.6	114.9	140.8	64.3
Industry - oil	30.1	79.1	160.1	11.2	259.7
Industry - gas	0.2	0.3	0.2	0.3	0.2
Residential/commercial - coal	0.2	0.0	0.0	0.0	0.0
Residential/commercial - oil	19.6	7.3	10.11	5.5	9.2
Residential/commercial - gas	0.3	0.3	0.3	0.3	0.3
Fuels/extraction, processes and distribution	0.7	0.9	1.2	0.6	1.5
Transportation	57.3	104.6	105.8	149.5	150.9
Nonferrous Metals	1737.2	398.7	399.8	426.0	431.6
Other	359.6	321.6	345.3	258.8	340.3
Total	2423.0	1510.5	1641.4	1465.0	1667.6

[a] HWOP denotes high world oil price scenario.
[b] LWOP denotes low world oil price scenario.

Emissions offsets ("tradeoffs") policies are presently being decided on a case-by-case basis; among the unsettled issues are whether certain generic source categories are to be allowed as potential tradeoffs, and what tradeoff ratios should apply. Some jurisdictions have local new source review (NSR) rules that consider HC, NO_x, and SO_x as precursors to secondary particulate formation. Therefore, these rules require that these gaseous pollutants be offset in addition to primary particulates when siting in areas which are nonattainment for particulate matter. In fact, offsets are "far and away the most disputed issues in new power plant siting cases," according to the California Air Resources Board (CARB).[7] Preliminary regulations have been drafted which would permit "banking" of valuable potential offsets which might not otherwise be available and thus might delay progress toward attainment.[8]

One consequence of NSR rules has been to inhibit repowering and cogeneration at some existing facilities where Best Available Control Technology (BACT) and offset requirements render the project marginal or unsound from the applicant's economic standpoint. However, given that the demand would otherwise be met by a new plant, these alternative options--from a public welfare standpoint--are more efficient, cheaper, and usually have net air quality benefits over the conventional approach.[4]

Nevertheless, new plants of any type will burn cleaner than old plants, due in part to the federal and local NSPS but more as a result of the "technology-forcing" influence of NSR rules[9]. In addition, siting of new plants outside urban areas will further decrease direct population impacts of energy production. But while this option may avoid some local air quality regulations, low emissions tradeoff potential will constrain rural siting in some areas. In a recent decision regarding the siting of a coal-fired power plant, the California Energy Commission (CEC) and the California Air Resources Board (CARB) established the Japanese selective catalytic reduction process (SCR) as BACT for NO_x which in tests has achieved a 90% reduction in NO_x emissions.[10] If this determination is sustained in practice, capital and operating expenditures for NO_x control will increase and will probably be an issue between utilities and regulators in all new California plants; however, it will make siting in nonattainment areas more feasible, since the magnitude of the emissions to be offset will be reduced.

Prompted in part by the extensive geothermal development proposed for the state, California has promulgated an H_2S standard based primarily on the compound's nuisance potential. Although the Stretford scrubbing process has been proposed for control of H_2S in geothermal operations, BACT has not yet been determined. Much of the proposed geothermal development is in the areas with hot water resources rather than dry steam, and--depending on the technology chosen--H_2S control may be a factor in geothermal development.

From the air quality standpoint, the capacity goals set forth under NEP-II and sited as for the RIIA exercise do not appear severely constrained at this time. The uncertainty which will probably be most limiting is visibility--at least near Class I areas.

Industry

Unlike eastern industrial boilers, very few boilers in the region were designed to burn coal; therefore "coal conversion" will mean new furnaces--not retrofits--and must provide for all the activities that are ancillary to coal use, such as storage and handling of coal and wastes. It is true that tradeoffs are most easily obtained in small increments, but small boilers are typically less efficient and emit more pollution per unit heat input than large boilers. Although new fluidized bed combustion technologies promise versatile, clean, and efficient heat-transfer operations of varying scale and application, emissions regulations requiring state-of-the-art control equipment may disadvantage the smaller user as new systems will likely be manufactured to the specifications of large generic boilers.[1]

Predicted county-by-county industrial fuel use patterns exhibit significant increases in direct coal use. While the rate of coal use at the state or regional level may appear reasonable, especially when compared with other areas of the country, the feasibility of achieving the levels projected is much less certain than for the utility sector. Los Angeles, Orange and San Bernardino Counties in the South Coast Air Basin account for the bulk of the new coal use. By 2000, new coal in Los Angeles county alone, some 82 x 10^{12} Btu, will be larger than the total base year industrial energy use in Arizona and Nevada combined. Clearly, it is the projected distribution rather than the extent of coal penetration which is more uncertain.

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WATER AVAILABILITY AND QUALITY CONSIDERATIONS AFFECTING ENERGY FUTURES IN FEDERAL REGION IX*

M. El Gasseir

INTRODUCTION

This research is part of the Regional Issues Identification and Assessment (RIIA) project.[1] Specifically, we seek to identify and assess the water availability and water quality issues resulting from the implementation of certain national energy plans, represented by a set of two Department of Energy (DOE) scenarios based on the Second National Energy Plan (NEP-II). LBL's responsibility is limited to Federal Region IX, which consists of the states of Arizona, California, Hawaii, and Nevada.

This research has two long-term objectives. The first is to identify and evaluate the water-related issues and impacts of each energy scenario. The second objective is to establish and update a water and energy information base, so that the

* This work supported by the Regional Impacts Division, Office of the Environment, U.S. Department of Energy under contract No. W-7405-ENG-48.

RIIA process is improved as it progresses from one scenario to another. The lack of an adequate centralized information base and the complex nature of the "energy/water interface" have necessitated the adoption of the second objective, as well as a selective approach to the analysis of the energy and water issues.

ACCOMPLISHMENTS DURING FY 1980

The prospects for energy development as constrained by water resources in Region IX were investigated. The water situation in Region IX is characterized by these features:

- The natural water supply is more constrained than in most of the other regions.
- Water resources are already highly developed, leaving little opportunity for further flow regulation or diversion.
- Population growth has burdened an already strained water supply.
- Public awareness of the increasing water scarcity is growing. This situation was brought about by the following factors: the 1976-1977 drought; delays and cancellations in federal reservoir-construction activities; Indian lawsuits over the acquisition and use of water resources; intrastate rivalries with respect to flow diversion and interbasin transfers; and a common concern over the environmental impacts of water development projects.

Water Quality

A number of federal and state policies seek to eliminate the discharge of pollutants to navigable waters by 1985. Although uncertainties exist regarding how strictly the U.S. Environmental Protection Agency intends to implement Public Law 92-500 and subsequent amendments, the zero-discharge policies aimed at new point-sources will continue to be in effect at the state and local levels. The energy industry has generally demonstrated its willingness to abide by these policies in its development plans.

In Region IX, routine pollution of surface waters by new point-source facilities should no longer be an issue. Operating under zero-discharge conditions means the consumption, on-site, of all withdrawn water. This raises two kinds of problems:

1. Increased water consumption and its implications.
2. The generation of additional solid-waste loads and the attendant disposal requirements and problems, including possible contamination of groundwater resources underlying the solid-waste disposal sites and the containment of surface runoff from the disposal areas.

Since the passage of Public Law 92-500, considerable progress has been made in controlling pollution from point sources. In many areas, the major sources of water pollution belong to the nonpoint-source category. The contribution of energy activities to nonpoint-source pollution is almost exclusively confined to the urban areas where most of this pollution is associated with the transportation sector. Rain-out of air pollutants affects plant life as well as water quality and is a significant issue in parts of the U.S.

Electricity Generation

The only water-intensive energy facilities specified by the NEP-II scenarios for Region IX are steam-electric power plants. In 1975, the existing plants provided about 70% of the region's baseload capacity. Cooling accounts for essentially all of the consumptive water requirements of such a power plant. Most of the existing thermal generating capacity in Region IX is on the coast, and typically uses ocean or estuarine water for once-through cooling. However, there are no plans to use ocean water as a medium for disposing of excess heat from new power plants. The dominant sources of cooling water for existing inland power plants are groundwater and surface water from aqueducts as well as directly from rivers. Treated sewage effluent is becoming a significant source of cooling water.

Information obtained from utility companies indicates that the most commonly used device for cooling new plants is the evaporative mechanical draft tower. Typically, cooling effluents (the blowdown) wil be disposed of by evaporation in lined holding ponds. Some utilities plan to use part of the cooling effluents in other on-site uses. Few plans call for nonroutine small releases of treated effluents to nearby surface waters.

The electric-power cycle that is most water intensive and the least flexible with regard to siting and water availability is the extraction of heat from liquid-dominated geothermal fields. In some cases, nontraditional sources of cooling water, such as agricultural waste water, appear to be available. In other locations, the prospects of finding adequate sources of nontraditional cooling water are not encouraging. The technologies of wet and dry cooling--through which water consumption can be reduced significantly--may eventually provide the solution.

Nontraditional Sources of Cooling Water

A number of alternatives to the use of freshwater for cooling, such as treated urban waste water, agricultural drainage, and brackish groundwater, are being investigated. Treated waste water is already being used by utilities in California and Nevada. According to present utility plans, within ten years, a capacity of 6,257 MW will utilize this resource in Federal Region IX. The major advantages of using treated urban waste water are its relative availability, especially near the electricity demand centers; the moderate competition for its acquisition and use; and its adequate quality and reliability of supply. The major advantage agricultural drainage offers over treated urban waste water is its presence in areas relatively free of siting constraints relating to seismicity, public safety, or air quality. However, until systems of collection and storage are constructed, agricultural drainage water will not be used for power-plant cooling. Brackish ground water is the least important of nontraditional sources of cooling water. The major problem is the lack of sufficient information on its availability for use as a coolant.

Water Availability

The availability of water for the steam-electric power plants projected to be built in the region was assessed. The results indicate:

- In Region IX, between the years 1990 and 2000, water consumption for power-plant cooling would increase five-fold. For a region where further water development is severely limited, the provision of more than 500 thousand gallons per day of freshwater for the purpose of cooling power plants is not likely to take place.
- The state with the lowest growth in cooling-water requirements is Arizona, due in part to an initially high level of water consumption by power plants.
- The average annual growth rates of cooling-water requirements for California, Hawaii, and Nevada are quite high (43%/yr, 65%/yr, and 49%/yr, respectively). In Nevada and to a lesser extent in California, the new requirements probably will not be satisfied largely through the consumption of freshwater.

By comparing the calculated consumptive water requirements with information on historic and projected water supply and demand, we concluded that in the following counties the impacts of the NEP-II scenario would be most significant:

- Arizona - Apache and Maricopa Counties,
- California - Butte, Imperial, Inyo, Lake, Merced, Mono, and San Bernardino Counties,
- Hawaii - Hawaii County,
- Nevada - Churchill, Eureka, Humboldt, Pershing, and Washoe Counties.

PLANNED ACTIVITIES FOR FY 1981

A study of a larger number of western states has been initiated in cooperation with Los Alamos Scientific Laboratory. This study will develop a set of scenarios describing future energy, economic, and demographic growth in the regions, and will provide an assessment of the water resource consequences.

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URBAN AND COMMUNITY IMPACT ANALYSIS*

H. Ruderman, F. Fung, and R. Beran†

INTRODUCTION

The U.S. Department of Energy (DOE) is required to prepare an urban and community impact analyses for each proposed major policy and program initiative. The statement's purpose is to identify the likely effects of these programs and policy initiatives on cities, counties, and communities. The analysis is intended to insure that potentially adverse impacts of proposed federal activities will be identified during the decision-making process.

The DOE has promulgated criteria for determining whether proposed activities must undergo an urban and community impact analysis. These criteria are based in part on the anticipated social and economic impacts of the activity on the community and the nation. Impacts include both direct and indirect effects on employment, population, income, cost of living, and state and local government finances. Differential impacts on central cities, suburban areas, nonmetropolitan communities, areas with high and low unemployment, and minority and low-income communities are to be analyzed quantitatively wherever possible. The criteria require an evaluation of aggregate effects on the U.S. economy--in terms of employment, personal income, prices, and fiscal conditions--and on the economy's major industrial sectors.

In the work reported here, we used clustering methods to select typical regions of the country for the impact analysis. Communities and urban areas within these regions were then selected for further detailed analysis, which was performed at DOE and other national laboratories. The LBL phase of the analysis was begun and completed during FY 1980. A more detailed account of this work may be found in LBL-11084.[1]

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ACCOMPLISHMENTS DURING FY 1980

Clustering analysis was performed on a set of 15 variables for each of the Bureau of Economic Affairs (BEA) regions of the country (see Table 1). These data summarize each region's demographic, economic, financial, and energy production characteristics.[2] Standard clustering methods[3,4] were used to group the regions into aggregates with similar characteristics. Careful attention was paid to using robust statistical techniques and validating the results. Six clusters were found

Table 1. Variables for clustering.

Extensive	Intensive
	Demographic
Area	n.a.
Population*	Population density*
n.a.	Percent nonwhite*
n.a.	Percent population change, 1970-1975*
	Urban - Rural
Urban land area	Percent urban land
Central city population	Percent population in central city*
Outlying area population	Percent population in outlying area*
Urban vehicle miles traveled	Per capita urban VMT
Rural vehicle miles traveled	Per capita rural VMT
Single-family dwellings	Percent single-family dwellings
	Employment
Civilian labor force	Labor participation rate*
Total employment	Unemployment rate*
	Personal Income
n.a.	Median household income
n.a.	Percent annual change 1969-1974
n.a.	Percent below poverty level*
n.a.	Percent above $15,000*
	Economic
Total retail sales	Per capita retail sales
Total wholesale sales	Per capita wholesale sales
Value added by manufacturers	Per capita value added
Electric generating capacity	Per capita capacity
Commercial landings and takeoffs	Per capita landings and takeoffs
	Energy Consumption
Residential and commercial	Per capita consumption
Industrial	Per capita industrial
Transportation	Per capita transportation
Coal	Per capita coal
Petroleum	Per capita petroleum
Natural gas	Per capita natural gas
Electricity	Per capita electricity
	Energy Production
Total coal	n.a.
Crude petroleum*	n.a.
Natural gas*	n.a.
Strippable coal reserves*	n.a.
Underground coal reserves*	n.a.
	Government Finance
Local government--general expenditure	Per capita expenditure
Intergovernmental transfers	Per capita transfers
n.a.	Per capita debt*

*Used in final clustering
n.a.--not applicable.

which contain 161 of the 173 BEA regions that cover the country; the other 12 could not be classified. The six clusters exemplify a broad range of characteristics: There are distinct differences between the racial compositions, income levels, population growth rates, unemployment rates, and resources for energy development in different clusters.

Using density estimate techniques,[5] we selected several BEAs from each cluster which are representative of the cluster as a whole. These modal BEAs lie close to the maximum of the estimated density in the cluster. The six clusters and their modal BEAs are shown in Table 2. Five of the clusters are composed primarily of rural BEAs in which we expect the largest impacts of synfuels development. They are distinguished by differences in their economic and demographic characteristics as well as in their resources for energy production. Modal BEAs in each of the clusters contain fossil or biomass resources needed for producing synthetic fuels. These BEAs are suitable for studying the impacts of a variety of technologies in a single community, or the impacts of a single technology over a range of communities.

Table 2. Modal BEA regions.

Cluster	Code	Region	Density*
1	123	Lubbock, Tex.	0.461
1	125	Abilene, Tex.	0.416
1	110	Wichita, Kans.	0.367
1	88	Eau Claire, Wis.	0.315
1	86	Wausau, Wis.	0.308
1	92	Grand Forks, N.Dak.	0.286
1	124	Odessa, Tex.	0.279
2	76	South Bend, Ind.	0.926
2	75	Fort Wayne, Ind.	0.884
2	82	Rockford, Ill.	0.868
2	69	Lima, Ohio	0.770
2	105	Waterloo, Iowa	0.633
2	89	La Crosse, Wis.	0.614
2	78	Peoria, Ill.	0.609
3	54	Louisville, Ky.-Ind.	1.000
3	57	Springfield, Ill.	0.731
3	16	Harrisburg, Pa.	0.716
3	64	Columbus, Ohio	0.703
3	10	Erie, Pa.	0.657
4	119	Tulsa, Okla.	0.887
4	28	Greenville, N.C.	0.804
4	49	Nashville, Tenn.	0.770
4	137	Mobile, Ala.	0.719
4	20	Roanoke, Va.	0.697
4	25	Greensboro-Winston Salem, High Point, N.C.	0.696
5	107	Omaha, Nebr.; Iowa	0.923
5	70	Toledo, Ohio; Mich.	0.849
5	85	Appleton; Oshkosh, Wis.	0.844
5	60	Indianapolis, Ind.	0.797
5	62	Cincinatti, Ohio; Ky.; Ind.	0.733
5	21	Richmond, Va.	0.729
5	157	Portland, Oreg.; Wash.	0.681
6	147	Colorado Springs, Colo.	0.278
6	146	Albuquerque, N.Mex.	0.269
6	145	El Paso, Tex.	0.226
6	151	Salt lake City, Utah	0.207

*Density estimates show the relative compactness of the clusters.

A sensitivity analysis of the clusters to a variety of clustering methods indicated that the clusters that we found are not unique. Only two of the clusters are distinct; the other four appear to be compact regions in a single large diffuse cluster. The modal BEAs, however, tend to group together as the clustering method is changed. They are relatively stable compared to the clusters, and thus form a valid set of regions for impact analysis.

Because we are unable to find a unique set of clusters, we are limited in the extent to which we can generalize the impact analysis results. We believe that the results can be extended only to those BEAs that consistently cluster with the ones on which the analysis was done. For the data we used, the results are applicable to only 34 of the 173 BEA regions.

PLANNED ACTIVITIES IN FY 1981

This work was concluded in FY 1980 and will not continue in FY 1981.

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ENERGY EFFICIENCY STUDIES

BUILDING ENERGY PERFORMANCE STANDARDS FOR RESIDENTIAL BUILDINGS*

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INTRODUCTION

In August of 1976, Congress passed the Energy Conservation Standards for New Buildings Act.[1] This Act mandated the development, promulgation, implementation, and administration of energy performance standards for all new buildings constructed in the United States after 1981. In August 1979, the U.S. Department of Energy (DOE) released a Notice of Proposed Rulemaking pursuant to this legislation. The importance of the proposed Building Energy Performance Standards (BEPS) in the residential sector is underscored by the fact that their observance could accomplish the following:

- Reduce energy use for space conditioning by 30%-40% from current building practice (or 60%-70% from the energy use in an average house built before the OPEC oil embargo of 1973).
- Produce a net savings in life-cycle costs of more than $1,000 for an average new homeowner.

Lawrence Berkeley Laboratory has played a key role since 1979 in supporting the development of these standards. The largest portion of the LBL research effort has been devoted to single-family residential buildings, the subject of this article. The research on commercial buildings and on the implementation of BEPS is reported in separate articles in this volume.

METHOD OF APPROACH

The approach followed in the analysis of residential building energy performance standards includes the following phases:

1. Development of residential prototypes;
2. Selection of conservation measures to be evaluated;
3. Description of standard building operating conditions;
4. Development of economic data, projections, and assumptions;
5. Computer simulation of building energy requirements in different climatic regions;
6. Analysis of life-cycle costs of energy conservation measures;
7. Sensitivity analyses of building characteristics, operating conditions, conservation measures, and economic parameters; and
8. Analysis of impacts of alternative energy budget levels, in which the alternative budget levels are based on phases 1 through 7.

The basis of our analytic method is life-cycle cost analysis. The objective of achieving a minimum in life-cycle costs is a reasonable basis for establishing energy conservation policy, because it provides a rational framework for trading scarce energy resources for other resources (e.g., labor and capital) in achieving a particular goal (in this case, space conditioning in residential buildings).[2] The use of an economic approach to energy conservation--and the increasing public awareness of how economics can help resolve issues--can be greatly enhanced by a government decision to use life-cycle costing as a major element of its energy conservation policy. Details of the approach, assumptions, and data used to carry it out can be found in References 3, 4, 5, and 6.

RESULTS

Figure 1 provides a useful summary of the results of LBL's analysis of the impact of energy conservation measures in residential buildings.[7] The upper curve, labeled "U.S. Stock, Dole 1970," is an estimate of the fuel requirements for space heating the 1970 stock of houses in the United States. A typical gas-heated house in Chicago, constructed before 1970, consumed approximately 110 x 10^9 joules/100 m^2 in one year. The fourth curve from the top, labeled "HUD Current Practice (DOE-2)," is an estimate of the space-heating energy use of a typical house constructed in 1976. The results in this curve were obtained by simulating the energy performance of a typical new house on the DOE-2 computer model. A typical house in Chicago constructed in 1976 used about 65 x 10^9 joules/100 m^2 in one year.

The fifth curve from the top, labelled "LBL optimum: High Infiltration (DOE-2)," contains the results of the life-cycle cost analysis for gas-heated houses, with an infiltration rate of 0.6 air changes/hr. This curve corresponds to the energy use mandated by the proposed Building Energy Performance Standards. A typical house in Chicago would consume about 45 x 10^9 joules/m^2 for gas heating. This curve was established by choosing the minimum in life-cycle cost for only widely available energy conservation measures for the envelope of

* This work is supported by the Standards Branch, Buildings Division, Office of Buildings and Community Systems, U.S. Department of Energy under Contract No. W-7405-ENG-48.

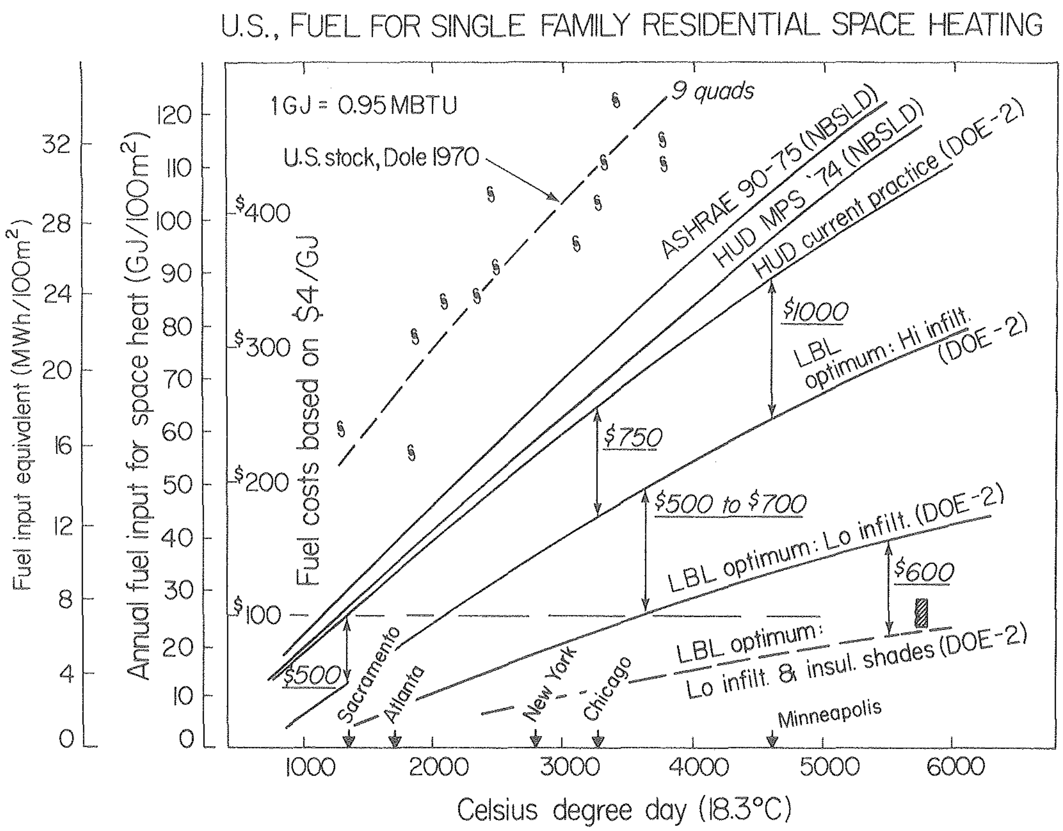

Fig. 1. Fuel use for single-family residential space heating. (XBL 795-1396)

the house. For Chicago, this corresponds to the use of R-38 ceiling insulation, R-27 wall insulation (i.e., insulated wall cavity and a sheet of insulating sheathing on the outside of the building), and triple glazing (or double glazing with a storm window). An important additional measure that could save substantial heating energy is the reduction of infiltration rates from 0.6 to 0.2 air changes per hour. For this case, the assumption is made that mechanical ventilation through a heat exchanger restores the outside air-exchange rate to 0.6 air changes per hour, to safeguard the quality of indoor air. (If the heat exchanger is 75% efficient, then the rate of heat loss by air infiltration would correspond to that of a house with 0.3 air changes per hour by natural ventilation). The energy use of a house with these measures is shown in the curve labelled "LBL optimum: Low Infiltration (DOE-2)." The annual gas-heating requirements of a Chicago house with low infiltration levels and conservation measures consistent with minimum life-cycle costs are about 22 x 10^9 joules/$100m^2$. Our estimates indicate that the construction of such an airtight house is cost-effective at the present time in most locations. The key barriers to such construction are (1) the availability of reliable residential heat exchangers, and (2) the lack of knowledge of the building industry and home buyers about the benefits of heat exchangers in saving energy and tight building construction and capital.

Other measures can further reduce the energy use in buildings. One example is shown in the bottom curve (Fig. 1), in which the conventional energy conservation measures used to derive the minimum in life-cycle costs and reductions in infiltration rates are combined with user-operated insulating shutters. Other user-operated devices or good energy management practices (such as setting the thermostat lower at night) can save energy. Passive solar techniques (direct gain, with increased glazing area on the south, and heavy mass in the building; attached greenhouses; and Trombe walls) can be combined with conventional energy conservation measures to achieve energy-use rates corresponding to those shown in the sixth and seventh curves, with a reduction in the requirements for conventional conservation measures and a reduction in air infiltration rates. Alternatively, conservation measures, infiltration reduction (with heat exchangers), user-operated energy management devices, and passive solar features can be combined to reduce space-heating energy requirements to low levels in almost all U.S. locations.

Figure 1 indicates that large energy savings can be accomplished by requiring all new houses to use all commonly available cost-effective energy conservation measures. BEPS can result in a substantial improvement in the thermal integrity of new houses in the U.S., and at the same time can save the consumer money. The magnitude of the energy savings is great enough to make a major contribution toward reducing U.S. energy demand growth. (About 35% of the energy in the nation is consumed in buildings, and about half of this is consumed in residential buildings.)

If the levels in the proposed BEPS (based on LBL's analysis, shown in the fourth curve "LBL Optimum: High Infiltration") are in fact observed in new residential buildings, then

- A reduction of 30% to 40% (from current building practice) in the average energy use for residential space conditioning will be accomplished. This is a reduction of 60% to 70% from the energy use of an average existing house, built before the 1973 OPEC oil embargo.

- Simple payback on conservation investment will occur in one to four years for electric heat and three to ten years for gas heat;

- An increased investment of $0.50 to $1.00 per square foot for a new house will be required (i.e., an increased initial investment of 1.5% to 3%); and

- The new homeowner will achieve a net savings of $800 to $1500 over the term of the house mortgage, in addition to a higher selling price for the house.

If the list of conservation measures is expanded to include just one conservation technology (reduced air infiltration combined with mechanical venting through a heat exchanger), then

- A reduction of 50% to 60% in average energy use for residential space conditioning (from current building practice) can be accomplished. This is a reduction of 75% to 85% from the energy use of an average existing house;

- This requires an increased initial investment of $0.75 to $1.50 per square foot.

- The net savings is $1500 to $4000 to the new house owner, in addition to a higher selling price for the house.

PLANNED ACTIVITIES IN FY 1981

Four major activities are to continue through FY 1980 and 1981. They are described in the following paragraphs.

1. Analysis of Life-Cycle Cost Minima in 32 Cities

For the Notice of Proposed Rulemaking, only ten cities were analyzed to set the BEPS. This was an inadequate sample with respect to the weather variation throughout the nation. The analysis is therefore being extended to 32 cities. Additional prototypes are being evaluated. In the previous analysis, the DOE-2 computer model did not have the capability to evaluate the annual energy efficiency of heating and cooling equipment. This capability now exists and will permit an assessment of the effect of climate and building thermal performance on the efficiency of air conditioners, heat pumps, and furnaces. In past work, DOE-2 was not used to model the insulation in foundations. An approach has been developed to perform this simulation; results of this work will make it possible to specify cost-effective levels of insulation for residential buildings with different types of foundations.

2. Analysis of Weather Regions for Promulgation of the Standards.

LBL is involved in assessing the best ways to promulgate the standards. This is a complex task, in which the need for simplicity in implementing BEPS must be balanced by the need to obtain accurate and reproducible results consistent with appropriate benefits and costs for a given locale. Several proposals have been put forward:

1. Perform regression analyses on energy budgets against weather variables and promulgate energy budget levels resulting from this analysis. (This is the approach followed in the Notice of Proposed Rulemaking.);

2. Perform regression analyses of the energy budget levels against both weather variables and local energy prices;

3. Permit the local builder to perform his or her own life-cycle cost analysis, based on the energy performance results from the DOE-2 simulations and local energy prices; and

4. Divide the country into a small number of weather regions, assuming each location employs the same conservation measures, corresponding to the energy budget level proposed by DOE in its BEPS proposal.

All of these approaches have some difficulties. The first three approaches--to the extent that they provide information only on energy budget levels and not on the conservation measures to be used to meet BEPS--result in a regulation that does not communicate the information needed by the builder in selecting conservation measures. The fourth approach, to the extent that it provides only one acceptable set of conservation measures, is not in keeping with the performance nature of BEPS. Combining the fourth approach with one of the first ones can be made difficult by the large number of regions that could result, thereby reducing or eliminating the simplicity of the fourth approach. A full analysis of all these possibilities (including mixed approaches) will be undertaken.

3. Manual of Recommended Practice

A method of promulgating the standards in keeping with the need for simplicity (to communicate effectively with the local building code official and builder) is to present both a set of energy conservation measures that meet the standards and to provide, in simple form, necessary data to allow the builder a wide variety of alternative approaches. Such an approach is under development at LBL. The approach is termed "precalculated tradeoffs," because it relies on the results of computer simulations of houses to assure that they meet the energy budget levels of the regulation. Some of the measures incorporated into the trade-offs include active solar water-heating systems; improvements in heating and cooling equipment efficiencies; redistribution of windows to the south face of the building to increase solar heat gain; other passive solar measures; changes in window area; reduction in air infiltration rates; dif- ferent shading devices for windows; alternative levels of wall, ceiling and floor insulation; different numbers of glazings; and other conservation approaches. To the extent possible, the presentation will be in terms of simple additions and subtractions that can be performed to represent any combination of energy conservation measures to be used.

4. Analysis of Market Behavior and Energy Conservation

Data are becoming available to characterize residential builders' energy conservation practices. Both cross-sectional and time-series data can provide insights into patterns of energy conservation investment over time and in different locations. A full set of data can reveal (1) the investment criteria of the decision-maker in the purchase of energy conservation (which may be expressed in terms of an implicit discount rate); (2) how these criteria have changed over time (revealing the market's responsiveness); and (3) how the decisions on energy conservation correspond with decisions in a perfectly functioning market. A quantitative analysis to evaluate these effects is underway, based on the computer simulations of residential energy use of houses constructed in the U.S. and on appropriate economic variables.

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DETERMINANTS OF RESIDENTIAL ENERGY USE*

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INTRODUCTION

Lawrence Berkeley Laboratory, in conjunction with a number of other cosponsoring organizations,[1] is investigating residential energy consumption in the City of Davis, California. Data from this project are being used as input to the DOE-2.1 energy-use model to validate the model's energy-use estimates for residential buildings. The project data will allow validation checks for projections of hourly and weekly electricity use, and monthly electricity and gas use. The project is also investigating a model of residential energy consumption that combines physical data on buildings, appliances, occupants' behavior, occupants' attitudes, demographics, and weather variables.

DATA COLLECTION

During the summer of 1980, 241 surveys were administered to a systematic random sample of Davis residents. The survey form consisted of two sections. The first section tallied information on the resident's lifestyle, demographics, energy-use attitudes, energy knowledge, and appliance-use behavior. The second section gathered information on the building, including type of wall construction; building orientation; wall, window, floor, and ceiling areas. The survey was administered by paid interviewers who received building audit

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training by a Pacific Gas & Electric Company (PG&E) auditor.

The sampling area was defined by the boundaries of a PG&E circuit that serves approximately 2,000 customers. This circuit was selected because more than 95% of the circuit's load was residential with only a small (540) commercial customers' contribution. PG&E is recording electricity readings each half hour for the circuit. PG&E also has provided monthly billing information for the entire survey sample under the condition that their customer's billing information remain confidential. Weather data for the project is being provided by the University of California, Davis Campus Climatic Station, which is partially funded by a Department of Energy grant to gather detailed solar radiation data. Hourly data for all key weather variables have been supplied by the station for this project.

Since the primary goal of the project is to validate the DOE-2.1 energy model, detailed information on internal house temperatures along with infiltration rates were required. A subsample consisting of fifty houses was randomly selected from the larger sample to participate in a phase of the project that gathered continuous data on internal house temperatures. Also, weekly electric meter readings for the subsample were recorded for an eight-to-ten week period from mid-August through early October.

To characterize the infiltration rate of the houses, air pressurization measurements were taken with blower-door equipment made available by the LBL air-infiltration group. Air pressurization data was obtained for approximately 70% of the subsample.

ANALYSIS

The survey information along with the more detailed engineering data on the subsample houses will be used as inputs to the DOE-2.1 model. Prototypes for the DOE-2.1 analysis will be drawn from groups of houses that are statistically similar across a number of characteristics, such as floor area, window area, orientation, glazing area, and appliance ownership and use. Average building characteristics for these house groups will be used as DOE-2.1 inputs. These prototypes will be used to calculate electricity and gas demand over various time periods. Based on the hourly electricity profiles for the prototype houses and the number of housing types on the circuit, an hourly electricity demand curve will be synthesized by DOE-2.1 and compared to actual circuit data on an hourly, daily, weekly, and monthly basis. Gas use computations will be compared with actual monthly consumption.

The second component of the analysis is an attempt to combine engineering data with social science data to create a simple model of energy use for the residential circuit. For this type of analysis, the data are ordered according to their technical and behavioral characteristics. The model is based on the Twin Rivers, New Jersey experience and includes the following variables:

BENV = Occupant-mediated behavior of the building envelope, such as opening windows for night ventilation.

TENV = Technical characteristics of the building envelope, such as window, door, ceiling, and external wall area, and insulation levels.

AUI = An appliance use index containing the number and type of appliances present along with the number of house occupants.

T_a = Ambient temperature

T = Internal house temperature

Q = Energy consumption

PLANNED ACTIVITIES IN FY 1981

Data collection and preparation of the data for analysis have been the major activities since this project began in July 1980. Analysis of the data as described above will be the major effort in 1981.

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LIFE-CYCLE COST ANALYSIS OF COMMERCIAL BUILDINGS*

I. Turiel and M. Levine

INTRODUCTION

In November of 1979, the Department of Energy (DOE) issued a notice of proposed rulemaking containing energy performance standards for new buildings.[1] The proposed standards consist of energy budget levels for different classifications of buildings in different climates, expressed as an annual rate of energy consumption per unit area.

The data base that was used to determine the energy budget levels consisted of 1,661 commercial, institutional, and high-rise apartment buildings constructed during 1975 and 1976. These buildings were analyzed for design energy performance using a shortened version of the building simulation computer program AXCESS. One hundred sixty-eight of the above buildings were redesigned to reduce design energy use; the average reduction was 40%. For these buildings, the energy budgets are based on the fraction of redesigned buildings that could achieve a specified level of design energy use. Economic considerations, such as life-cycle costs or simple payback periods for energy conservation investments, were not considered to be criteria for the development of energy budget levels for commercial buildings, as was the case for residential buildings.

PROJECT PURPOSE

The purpose of this project is to perform life-cycle cost analyses for office buildings to establish energy budget levels based on minimum life-cycle cost. Office buildings consume about 20% of the primary energy used by institutional and commercial buildings in the U.S.[2] Figure 1 shows average annual energy use per square foot for office and three other nonresidential building types as a function of end-use. The three largest end-uses are space heating, cooling, and lighting, although their relative magnitudes vary from one building to another and from one location to another.

PLANNED ACTIVITIES FOR FY 1981

The project is subdivided into four tasks as follows:

- Task 1. Perform an energy analysis of a typical office building using the DOE-2.1 building energy-use model.[3] Compare results obtained to the previous analysis with AXCESS and to actual energy use in building.

  We have chosen an electrically heated and cooled six-story office building in Denver, Colorado to commence our analysis, and we plan to look at the original building and the original building as modified by such design options as daylighting, deadband thermostats, natural gas space heating and increased insulation.

- Task 2. Determine the ability of a daylighting algorithm being developed by LBL's Windows and Lighting Group to properly model the reduction in lighting energy-use through the use of natural daylight in building perimeters.

- Task 3. Conduct a life-cycle cost analysis of the Denver office building, using results of Task 1 and the DOE-2.1 computer program (modified by the addition of the daylighting algorithm).

  To perform Task 3, a new life-cycle cost model (LCCM) will be developed which will incorporate such features as time-of-day electricity pricing, peak power charges, and potential changes in tax burden to encourage energy conservation. (The contractor who will develop the LCCM has yet to be chosen.) Initial cost data for various design changes must be developed to allow for computation of life-cycle costs. The objective of this task is to rank the energy-conserving strategies and combinations of strategies according to economic criteria, such as life-cycle cost, payback period, and benefit-to-cost ratio.

- Task 4. Perform climate sensitivity analyses for energy use and life-cycle cost with Denver office building.

  An energy and life-cycle cost analysis of the Denver office building will be performed for five other locations both with and without heating, ventilation, and air conditioning system (HVAC) sizing changes. Regional fuel and conservation costs will be used for this analysis. A determination will be made of the number of hours that comfort conditions are not met as HVAC systems of different size are utilized.

Upon conclusion of Task 4, recommendations will be made concerning further planned life-cycle cost work. Tasks 1-4 are expected to be essentially completed by the end of FY 1981. A more extensive analysis similar to Task 4 will be performed in FY 1982. The sensitivity of life-cycle cost results to variations in building parameters will be studied in FY 1982. Additionally, a complete life-cycle cost analysis will be performed for a prototypical office building in FY 1982. The prototypical building will incorporate design features common to office buildings designed and built in 1979 and

* This work is supported by Standards Branch, Office of Buildings and Community Systems, U.S. Department of Energy under Contract No. 7405-ENG-48.

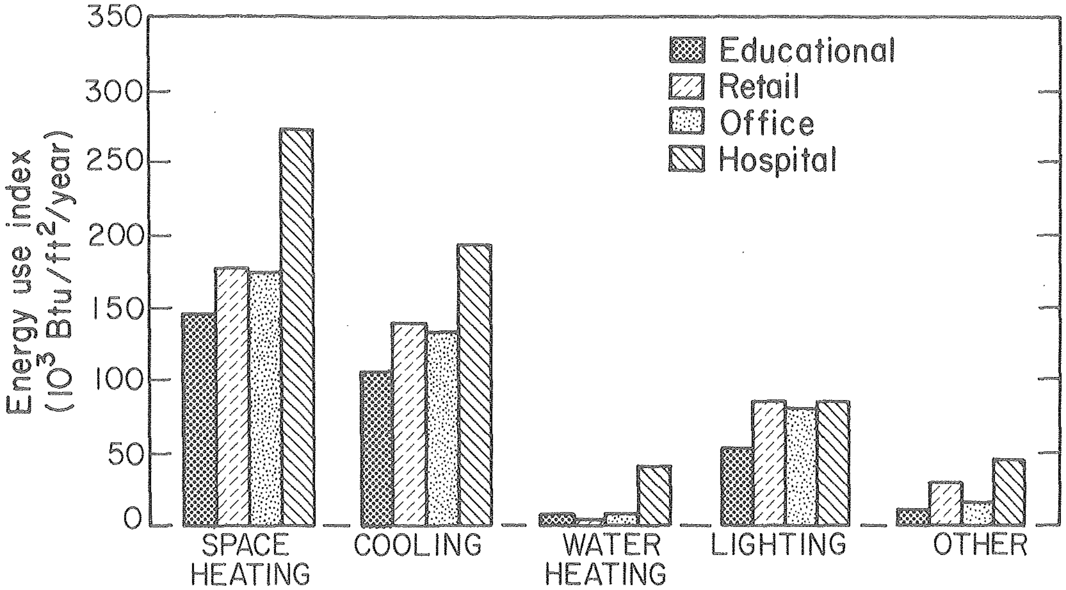

Fig. 1. Energy use indices for educational, retail, office, and hospital buildings, 1970. Data are from Oak Ridge National Laboratory's report, Commercial Energy Use, February 1978. Energy use is given in primary units. (XBL 7810-11637)

1980. Outputs from this project will be used in the Oak Ridge National Laboratory engineering-economic model of energy use for the commercial sector, which will provide estimates of the national impact of building energy performance standards on energy use.

PRELIMINARY RESULTS

The Denver office building, as originally designed and built in the 1975-1976 period, has been analyzed for annual energy consumption by end-use. The original building design is a six-story office building with the sixth floor cantilevered over the lower floors by approximately eight feet on each side of the building. The length of the building is oriented northeast to southwest, and the area is approximately 10^5 ft.^{2}. The glass area is approximately 25% of the total exterior wall surface. Glazing is recessed nine in. and is composed of two 3/16 in. sheets spaced 1/4 in. apart. Cooling and space heating are provided by a zoned, water-to-air unitary heat pump system with a circulating water loop. A 300 kW electric boiler provides back-up heat generation to maintain the water loop temperature above 60°F. The average lighting level is 2.6 W/ft^2.

Table 1 illustrates the results obtained at LBL from the use of two different building descriptions (1 and 2) assembled by two different architectural and engineering consulting firms. Also shown are the results of an energy analysis performed on the same building with the building simulation computer program known as AXCESS.[4] The input for that simulation is very similar to that in description 1 in Table 1. A 1976 weather tape was used for the AXCESS runs, and a 1971 weather tape was used for the DOE-2.0 runs; however, the energy required for space-conditioning for any one building description varies by only a few percent from year to year. This insensitivity of energy use to weather in office buildings is due to the fact that internal sources, such as lights and people, account for a large percentage of the cooling load and also satisfy some percentage of the heating load.

As can be seen in Table 1, the energy used for space conditioning as derived from the AXCESS simulation and from the first DOE-2.0 simulation is similar and accounts for approximately 44% of the total energy budget. Lighting accounts for about half of the total energy budget. Domestic hot water energy use has not yet been estimated.

Columns 2 and 3 summarize the results obtained from simulating the two different building descriptions on DOE-2.0. Description 2 results in 5% greater total energy use, but in much more significant differences for separate end-uses, particularly space heating. There are a number of differences in the two descriptions as regards important building parameters: For example, in description 2, there is no plenum and no use of layered materials to describe the external walls and roof. Differences in supply and outside air quantities and in infiltration schedules were remedied before the results shown in Table 1 were obtained.

Columns 3 and 4 illustrate the difference in results obtained when the same building input description is modeled on DOE-2.0 and DOE-2.1, an updated version of DOE-2.0. The total energy use is almost identical, however, large differences in end-use energy exist for space heating, cooling, and fans. A number of improvements have been made in the DOE-2.1 computer program as regards heat-pump operation and cooling-tower simulations that affect the results obtained.

Table 1. Annual site energy use (10^6 Btu).

	Building Description 1		Building Description 2	
End-Use	AXCESS (column 1)	DOE-2.0 (column 2)	DOE-2.0 (column 3)	DOE-2.1 (column 4)
Heating	⎤	863	1257	1631
Cooling	2140[a]	555	652	690[a]
HVAC Auxiliary	⎦	598	468	78[b]
Lighting	2612	2644	2584	2584
Elevators	94	94	94	94
Total	4846	4754	5055	5077

[a] For AXCESS 1, this figure is a composite of heating, cooling, and HVAC Auxiliary energy use.

[b] In DOE-2.1, cooling tower energy use is moved from HVAC Auxiliary to cooling as an end-use.

The effect of changes in various input parameters on a design energy budget is presently being investigated. Preliminary comparisons between two independent preparations of building input indicate that although total energy budget predicted by DOE-2.0 varies by only 5%, individual end-use components vary by as much as 45%. Similar results were obtained when DOE-2.0 and DOE-2.1 simulations were compared using the same input description.

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IMPLEMENTING BUILDING ENERGY STANDARDS IN CALIFORNIA*

R. Feinbaum

INTRODUCTION

From the beginning, research for the Building Energy Performance Standards (BEPS) has focused on technical aspects of standards development. Sophisticated computer models, based on extensive engineering and economic analyses, have been used to set cost-effective levels of energy conservation in new residential construction. Projections of the amount of energy, or the millions of barrels of oil, the nation might save then follow from a comparison of past building practices with practices expected to result from the standards.

The potential oil savings are quite large (as much as 1.5×10^6 bbl/day by the year 2000). But unless standards are enforced, those savings are unlikely to occur, and projections of energy demand are likely to be lower than actual demand. Thus, enforcement is essential for an effective standards program. The BEPS Notice of Proposed Rulemaking (issued in November 1979) charges local building departments with the responsibility for enforcement of energy regulations through the normal building permit approval process. But, if the locals are unable, or unwilling, to enforce the standards, the U.S. Department of Energy (DOE) is supposed to do so.

Although the DOE is still developing the BEPS (working toward a new proposed rulemaking in August of 1981), the State of California has had standards in place for the past two years. In fact, the state is now in the process of updating its residential standards to "better the BEPS." Thus the California experience with energy standards may give important insights into the implementation and enforcement problems likely to arise in a national effort to regulate building designs for the purpose of lowering energy consumption.

ACCOMPLISHMENTS DURING FY 1980

LBL initiated a case study of California building standards in January 1980. At the outset, the study population included the entire spectrum of participants in the building process. We considered the California Energy Commission's (CEC) intentions and actions to be vital to understanding the impact

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of California's Title 24 energy conservation regulations. We felt it was equally necessary to investigate the manner in which local building departments enforced the standards. (As with the BEPS, building officials were to see that the regulations were carried out.) The reactions of builders, architects, engineers also had to be discerned along with the attitudes of the "supporting actors"--realtors, financial institutions, utilities, and insurers--since they play an important role in the building community.

Much of the research has been focused on the energy commission's standards-setting process and the enforcement activities of the local building departments. Two basic techniques have been used. At the CEC, key staff and commissioners were interviewed; relevant documents were reviewed; and meetings of a task force (set up by the commission to investigate compliance) were monitored. A questionnaire was designed to use building officials' experiences and attitudes with respect to energy standards. The survey went to all 530 building departments in the state; the response rate of approximately 60% was especially good, given the survey's complexity and length. (About 30 minutes was required to complete it.) To supplement the information on the questionnaire, we interviewed selected local officials to understand better the role energy considerations have in building department activities.

The private sector's reactions have been explored with similar techniques. Interviews have been held with key figures in the building, architecture, utility, and banking fields. In addition, pilot studies have been completed with architects and builders. A questionnaire (comparable to the one given to building officials) was administered at a conference on energy-conserving design sponsored by the California Council of the American Institute of Architects. Slightly more than half of the 103 registered California architects responded. Representatives of 16 building firms were interviewed in depth concerning their experiences with state energy regulations. Interviewees were chosen from among various types of builders--large and small, custom and tract, innovative and conventional--to give a fuller picture of the industry's response to standards. In addition, magazines and newsletters read by builders and architects have been surveyed for the two years that the state's standards have been in effect.

Results

The major findings of the study may be placed in several categories; some findings relate to the standards themselves, some pertain to the Energy Commission's efforts to provide information and training; others related to enforcement at the local level, to acceptance by the private sector, and to reactions of the "supporting actors."

Standards

California's Title 24 standards have two sections, one dealing with residential buildings, the other with nonresidential buildings. Our primary mission has been to study reactions to the residential standards. Unlike the proposed BEPS, which is a performance standard, California's residential regulations are prescriptive in nature. Although trade-offs can be made, the vast majority of the state's homes are designed to conform to the component requirements, i.e., to a certain level of insulation, glass area, and furnace size. The nonresidential standards allow a performance approach with appropriate documentation. But building officials report that in only a small minority of the structures (2-10%) is an alternate approach to compliance with the regulations adopted.

The California Energy Commission has developed a procedure to certify local standards that differ from the state's. But only a few localities have tried to certify such standards. And those that have done so have usually mandated solar water heating or swimming pool heating, rather than to attempt sweeping revisions of the regulations.

Energy Commission Role

The Commission recognized the need to train building officials for effective enforcement. During the Spring, Summer, and Fall of 1978 (as the regulations were going into effect), CEC staff sponsored nearly 100 sessions to inform building departments and other interested parties about the regulations. Many officials felt that the sessions were helpful. But others criticized them as too heavily weighted towards theory; for trying to cover too much material in one session; for failure to answer specific questions; and for the convenors' lack of knowledge about local problems. CEC staff acknowledge many of these shortcomings. However, since the training program had to be put together hurriedly, the effort ought to be regarded as a qualified success.

CEC published a design manual to aid builders and local officials in complying with the regulations. But as Title 24 was to go into effect, the commission was sued by Building Code Action for alleged procedural violations and technical inaccuracies in the standards. A portion of the standards was stayed for nearly two years, until recently when the Court of Appeals ruled in the commission's favor. Since the manual was based on the original standards, portions of the manual have been incorrect for most of the time the regulations have been in effect. In addition, the commission itself made changes which were not quickly incorporated. Thus, the manual, which was to have been a main tool for compliance, lost most of its usefulness. Although the commission publishes a newsletter, the Blueprint, which notes changes in the standards, few people seem to integrate its (unofficial) interpretations with those of the manual.

CEC has never attempted to enforce the standards itself, even though the Warren-Alquist Act (the legislation which created the commission) gives it the power to do so in localities unable or unwilling to enforce the standards. Staff limitations have hampered any move in that direction. However in June of 1980, the commission appointed a task force to advise it on ways to gain greater compliance with the standards. One of the group's recently released recommendations is for development of a monitoring capability, but the suggestion has not been implemented.

Local Enforcement Efforts

Enforcement of energy standards varies throughout the state. Some departments check plans thoroughly, request redesigns for failure to comply with Title 24, and inspect for insulation installation. Other departments pay only minimal attention to energy conservation, accepting an architect's or engineer's stamp and certificates from insulation contractors in lieu of checking for compliance with the standards. Our questionnaire provides one measure of effort at the local level: the proportion of time departments spend in checking plans and inspection. About 25% of the building departments seem to be devoting a small proportion (less than 5%) of their time to energy conservation standards, while 20% seem to be treating enforcement more seriously (devoting 15% or more of their time to it).

A considerable number of building departments feel that they cannot adequately enforce energy standards because of a shortage of personnel. Shortly before Title 24 was to go into effect, Californians passed Proposition 13, which cut building department staffs. Although the energy commission authorized localities to raise fees to cover enforcement costs, most jurisdictions have been unable or unwilling to do so.

Few building officials can say whether buildings are in full compliance with Title 24. However, our questionnaire found that officals held several general impressions: Most of the official think that the standards are saving energy compared to the energy savings the market would have produced. And most believe that buildings in their areas just meet the standards; few builders provide more energy conservation than required or fail to include mandated features.

Local code officials generally feel "put upon" by higher levels of government. In California, not only have they recently been required to check for energy efficiency, but for seismic safety and for handicapped access as well. They see state and federal agencies mandating enforcement responsibilities without providing additional funds or staff so that the job can be done well. Building officials also worry about increased legal liability arising from their new responsibilities. No California department has been sued, but the possibility of legal action concerns many officials.

Private Sector Acceptance

Builders have gradually become resigned to energy standards. Most, however, still feel that the market will take care of energy conservation, given the expected price rises in the near future. Title 24 has not significantly changed residential design; basically, it has required added insulation and some limitation of glazing (as well as double-paned glass in some locations). Builders estimate that standards have raised the cost of a new home by 2-5%.

Architects generally dislike the state's prescriptive standards, and have been pushing for a performance approach to energy conservation. Engineers, by contrast, are more comfortable with a component approach, which allows trade-offs among design elements. The most innovative designers report the greatest amount of difficulty with current state standards. They sometimes find building officials reluctant to accept new ideas, and often are required to submit extensive calculations to satisfy Title 24 requirements.

Supporting Actors

There has been little action on the part of financial institutions to take account of energy costs in making loans for home purchases. Some banks and savings and loans institutions have financed active solar systems, and a few have backed builders of passive solar developments, but none have yet made a commitment to change loan qualification criteria to include the house's projected energy consumption.

The California Public Utilities Commission has urged the utilities to take major steps toward energy conservation. Some observers even feel that efforts by the utilities can play a greater role in saving energy in buildings than the CEC's standards. New programs tying "line extension credits" to conservation measures, and providing low- or even zero-interest loans to consumers for financing conservation measures are being readied for widespread use.

PLANNED ACTIVITIES FOR FY 1981

The California Energy Commission is currently in the process of up-dating its residential standards. Hearings should be held in December and January, with passage of new regulations likely to occur in the Spring of 1981. It is important to follow the revision process, and the new training efforts that will be employed, in order to compare the results with those of the previous efforts.

A number of innovative efforts are occurring throughout California. Several of these are of particular interest:

1. The city and county of Fresno's efforts to integrate land use and energy planning.
2. The effects of recently passed local solar-mandating ordinances in San Diego, Santa Barbara, and Santa Clara counties.
3. The reasons that builders' market advanced energy conservation homes.

We shall analyze these, and other innovative efforts, as a means of assessing policy options for energy savings beyond those provided in a standards program.

More systematic information will be collected --through questionnaires, and additional interviews, especially in Southern California--from builders and designers concerning their experiences with, and attitudes toward, state, and federal energy standards.

ECONOMIC BENEFITS AND ENERGY SAVINGS OF APPLIANCE EFFICIENCY STANDARDS*

J. McMahon and M. Levine

INTRODUCTION

The U.S. Department of Energy (DOE), working under the congressional mandate of the Energy Policy and Conservation Act, as amended,† has proposed a set of mandatory efficiency standards for eight types of consumer products. An appliance not meeting these performance standards cannot be sold in the United States. The residential appliances affected in the proposed rule are refrigerators and refrigerator/freezers, freezers, clothes dryers, water heaters, room air conditioners, kitchen ranges and ovens, central air conditioners, and furnaces. The mandated standards are supposed to achieve the maximum energy efficiency that is technologically feasible and economically justified.

ACCOMPLISHMENTS DURING FY 1980

A very large analytical effort was required to establish the technologically feasible engineering options, their cost, the appliances that consumers are likely to purchase in the absence of standards, and how appliance usage patterns may change. The effort was also designed to assess the effects of the standards as perceived by consumers in terms of equipment cost increases, fuel and dollar savings, and affects on the appliance manufacturers and their economic livelihood. Preliminary documents, published with the proposed rule, describe the analysis prior to the public comment period.[1-6] Subsequently, testimony from manufacturers, consumers, and interested parties has been obtained. Public comments and additional analysis will be incorporated in DOE's final recommendation of standards, to be published early in 1981.

One aspect of the analysis will be described here. The modeling of residential energy consumption to elucidate the proposed standards' economic and energy savings to the consumer involved the use of the Oak Ridge National Laboratory (ORNL) Residential Energy Demand Model.[7-11] This model was originally written by Eric Hirst and Janet Carney, and was subsequently modified at ORNL to include only those appliance types in the proposed regulation. The model has been used and further modified in the course of analysis at LBL.

ORNL Residential Energy Demand Model

Some key features of the ORNL model are that it details energy demand for the residential sector by treating each end-use separately, and that the efficiency of appliances can change over time in response to changing fuel prices. For each end-use (where appropriate), four "fuel types" are considered: electricity, gas, oil, and other. An additional level of detail is included (when supported by the data) by considering three housing types: single-family, multifamily, and mobile homes.

The essential inputs to the model include: initial estimates of energy consumption per unit; saturation of appliances in stock; new purchase market shares; thermal integrity of structures; elasticities of energy consumption to fuel price; engineering curves relating first cost to appliance efficiency; appliance lifetimes; initial capital cost of equipment; exogenous projections of housing stocks and new construction; anticipated fuel price increases; and income projection.

The most important calculations performed by the model, for each year of the projection period, include changes in efficiency of new appliances, thermal integrity of new structures, number of appliance installations, equipment costs, fuel costs, and energy consumption. Over the period, the present values of equipment, fuel, and total costs are calculated for each end-use.

One of the key elements of this analysis is the use of a life-cycle costing methodology[12] to determine the consumers' efficiency choice of appliance efficiency. It is assumed initially, based on historical evidence, that consumers have not minimized their life-cycle cost at a low discount rate when deciding which efficiency of a given appliance to purchase. The consumer's choice is modeled to move closer to a minimum life-cycle cost (at a reasonably low discount rate) as fuel prices increase. An alternative way of describing this is to say that the purchaser's implicit discount rate decreases as energy costs increase.

Energy Prices

Projections of energy prices are important because of their influence on the level of expected investment in energy conservation. The baseline is characterized throughout this analysis by two different sets of energy prices. The high price case assumes a 2.5% real annual escalation of electricity prices and 3.0% real annual increase of oil, gas and other fuel prices. The low price case assumes annual real price increases of 1.0% and 1.5%, respectively. Both energy price cases have the same initial prices for 1977.

Baseline Forecasts

The results of the energy demand forecasts are presented in Tables 1 and 2. In the high energy price case, primary energy demand increases from

* This work was supported by the Standards Branch, Consumer Products Division, Office of Buildings and Community Systems, U.S. Department of Energy under Contract No. 7405-ENG-48.

† By the National Energy Conservation Policy Act.

Table 1. Baseline demand forecasts: Total residential energy use. (in 10^{15} Btu's)

Year	High Energy Price Case	Low Energy Price Case
1978	17.03	17.01
1980	17.97	18.02
1985	19.52	19.84
1990	20.74	21.55
1995	21.58	22.98
2000	22.22	24.29

Table 2. Percentage 1982-2005 energy demand by end use.

End Use	High Price Case Base (%)	Low Price Case Base (%)
Central space heater	39.8	39.5
Home space heater	12.5	12.5
Room air conditioner	2.0	2.1
Central air conditioner	5.2	5.3
Water heater	18.2	17.8
Refrigerator	10.0	10.5
Freezer	3.3	3.4
Range	6.0	5.9
Dryer	3.0	3.0

Table 3. Energy demand reduction resulting from the proposed standards.

	High Price Case	Low Price Case
Energy Savings By Fuel Type, 1982-2005 (in quads*)		
Electricity	10.0	17.1
Natural gas	3.0	6.0
Oil	0.6	1.1
Energy Savings by End Use, 1982-2005 (in quads)		
Central space heat	2.00	4.27
Room air conditioners	0.22	0.56
Central air conditioners	2.62	3.73
Water heaters	3.87	5.91
Refrigerators	3.64	7.56
Freezers	0.82	1.69
Ranges/ovens	0.26	0.82
Clothes dryers	0.32	0.59
Annual Energy Savings (quads per year)		
1985	0.01	0.04
1990	0.61	0.89
1995	0.79	1.34
2000	0.80	1.59
2005	0.68	1.65

*Includes both regulated and unregulated products.

18 quads* in 1980 to 22.2 quads in the year 2000 (an average growth of 1.1%/yr). In the low price case, 24.3 quads are consumed in 2000, representing an average growth of 1.5% per year. Table 2 indicates that the largest energy user in the residential sector is central space heating, representing 40% of the total primary energy consumed by the regulated products nationally. The next largest users are water heating, room space heaters, and refrigerators.

Energy Savings

Table 3 presents the reductions in primary energy demand estimated to be achieved by the Consumer Products Energy Performance Standards for the high and low price cases. These energy savings were obtained by subtracting the energy demand associated with the regulated consumer products in the standards case from that in the baseline case, with the price of energy the same in the two cases. These are the major findings of this analysis of energy savings:

- Measured at the building boundary, 46-49% of the energy savings is electricity; the remaining 51-54% of the savings is oil and natural gas;
- Measured in source energy units, 70-75% of the energy savings is electricity;
- The annual total energy savings in 1995 resulting from the Consumer Products Energy Performance Standards is equivalent to 0.4 to 0.8 million barrels of oil per day;
- Between 85 and 90% of the energy savings resulting from the standards is achieved by improving the energy efficiency of four end uses: water heating, refrigeration, central air conditioning, and central space heating.
- Measured as a percentage of total residential energy demand of the regulated products, the standards reduce residential

*1 quad = 10^{15} Btu and 1 kWh = 11,500 Btu.

energy demand by 5-8.4%; however, measured as a percentage of total residential energy demand growth, the standards are estimated to reduce growth after 1980 by 33-50% by the year 2000.

Reduction in Consumer Costs

The standards produce a net savings to the consumer of 15.2-19.3 billion dollars, excluding implementation and enforcement costs.* The savings on energy costs are estimated at 22-29 billion dollars; increased present cost of equipment is 7-10 billion dollars. The total economic savings are on net present value of equipment and energy costs of 950-1,100 billion dollars for the 1982 to 2005 period.

- The net present benefit to the consumer of the proposed standards is positive under the full range of sensitivity studies.
- The variables having the greatest impact on estimates of energy savings are the energy price escalation rates and the implicit discount rates that characterize the market response to higher energy prices.

PLANNED ACTIVITIES FOR FY 1981

The major tasks underway are incorporation in the model of public responses to the proposed rule and inclusion of newer user data and additional analyses. Subsequently, using the ORNL/LBL Model, new estimates will be made of energy consumption and economic and energy savings resulting from the final standards. Further research in data development and model improvements are recommended on the basis of the experience gained in this analytical effort.

*All net present value estimates are obtained by discounting future costs and benefits at a 10% (real) discount rate basis of the experience gained in this analytical effort.

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LIFE-CYCLE COST ANALYSIS OF MAJOR APPLIANCES*

I. Turiel, H. Estrada, and M. Levine

INTRODUCTION

The Energy Policy and Conservation Act (Public Law 94-163) as amended by the National Energy Conservation Policy Act (Public Law 95-619) established the Consumer Products Efficiency Standards Program and assigned the Department of Energy (DOE) the task of establishing mandatory minimum energy efficiency standards for 13 consumer products. In accordance with this requirement, DOE has proposed minimum energy efficiency standards for various classes of eight appliances: refrigerators and refrigerator-freezers, clothes dryers, water heaters, room air conditioners, ranges and ovens, central air conditioners, and furnaces.[1] The remaining five consumer products have been placed on a slower schedule with standards to be proposed at a later date.

DOE is required to set standards at a level that achieves the maximum improvement in energy efficiency that is technologically feasible and economically justified. One of the criteria on which this determination is based is the economic impact of the standards on consumers of the regulated products.

This paper provides a methodology for assessing the economic costs and benefits to the consumer who purchases appliances of varying initial costs and energy efficiency. The basis for the method of analysis is the use of life-cycle costing.[2]

The life-cycle cost of owning and operating an appliance is equal to the first cost or purchase price plus the operating and maintenance costs over the appliance's lifetime. The first cost may be paid when the product is purchased or the consumer may borrow money which is paid back with interest after the purchase is made. For the purpose of this analysis, it is assumed that the consumer makes a cash purchase of the appliance. The assumption is also made that the cost of maintenance over the appliance's lifetime is unchanged as the efficiency of a model is increased or decreased. Therefore, the maintenance cost is not included in the life-cycle cost calculation, as exclusion of maintenance costs has no effect on the differences in life-cycle costs among models of different efficiencies. In order to consider first cost and operating costs on a time equivalent basis, all future operating costs are discounted to present value.

A more energy efficient product is often more expensive than an otherwise identical product of low efficiency. However, the more energy efficient model uses less energy than a less efficient one and thus costs less to operate. If the more efficient model has lower total costs to the consumer over the life of the appliance, the consumer benefits, although a higher initial investment may cause an adverse impact over the short term.

This potential problem of higher first costs associated with lower life-cycle costs of more energy efficient products can be assessed in terms of a simple payback period. The simple payback period is the amount of time required for the consumer to recoup his or her additional investment in a more energy efficient product. For example, if the simple payback period is 11 months, then the extra costs of the purchase of a more efficient product are fully recovered in reduced energy bills during the first 11 months of operation of the product. This is equivalent to a return on investment of greater than 100% per year to the consumer. If, however, the simple payback period is 20 years, then the rate of return on the initial investment is small (unless energy prices escalate rapidly).

Because energy prices and appliance use patterns vary regionally, the imposition of national standards may result in an inequitable distribution of costs and benefits among regions. Since variations in energy consumption are most significant among space heating and cooling products, regional analyses will focus on gas-fired and oil-fired furnaces, central air conditioners, and room air conditioners.

METHODS AND ASSUMPTIONS

The total life-cycle cost (LCC) of an appliance is given by

$$LCC = IC + \sum_{i=1}^{N} (ENC)_i \times \frac{(PF)(1+f)^i}{(1+d)^i} \qquad (1)$$

where

IC = initial cost of appliance, in dollars,

ENC_i = energy consumption in year i, in million Btu's,

PF = fuel price in year 1, in dollars per million Btu's,

N = lifetime of appliance, in years

f = annual fuel escalation rate in constant dollars,

d = discount rate in constant dollars.

DOE is proposing two sets of energy performance standards for consumer products: one set applies in 1981 and a tighter set applies in 1986. The

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life-cycle cost analysis applies only to the 1986 standards, because the tighter 1986 standards are intended to achieve substantial life-cycle cost savings to the consumer. The 1981 standards achieve much smaller life-cycle cost savings because of the relatively small energy efficiency improvements mandated by these near-term standards.

In the analysis as performed, yearly energy consumption (ENC_i) and the fuel escalation rate (f) are assumed to be constant over the appliance lifetime. Thus, equation (1) may be simplified to

$$LCC = IC + (ENC) \times (PF) \times (PWF) \quad (2)$$

where

$$PWF = \sum_{i=1}^{N} \left(\frac{1+f}{1+d}\right)^{i} . \quad (3)$$

Table 1 shows the national average fuel prices and escalation rates used in the life-cycle cost calculations. Both a high and a low fuel price escalation rate are presented to illustrate the effects of differing price scenarios on life-cycle costs.* (These two price scenarios are used in the analysis to represent DOE's estimates of likely upper and lower bounds of fuel prices). Both the first cost and the fuel prices are expressed as 1985 prices measured in 1978 dollars: As such, the LCC results are expressed in constant 1978 dollars.† The fuel price escalation rates and the discount rate are expressed in real dollars, that is, as a rate above that of inflation. The discount rate was chosen to be 5%, real; sensitivity analyses for discount rates of 3% and 10% are discussed later. Table 2 presents the appliance lifetimes used in the LCC analysis.

There are two other very important inputs to the LCC computations: cost versus efficiency, and annual energy consumption for each class of appliance.

* The relative life-cycle costs and payback periods for products of differing energy efficiencies are not greatly changed between the two price scenarios. Only the high price case results are presented.

† At the time this article was written the authors expected the proposed standards to be effective in 1985. Therefore, the analysis was performed using 1985 fuel prices and a base case efficiency for each appliance projected to occur in 1985 without standards. Choosing 1985 as the year of purchase, yields results which are only a few percent different from those obtained if 1986 were the initial year of purchase. Throughout the remainder of this report, 1985 will be used as the year the standards become effective even though it now appears that January 1, 1986 is the correct date.

Table 1. Fuel prices and escalation rates.

	1985 fuel price in $/10^6 Btu (and 1978 $)	Annual escalation rate (percent)	
		High Case	Low Case
Electricity	15.70*	2.5	1.0
Gas	3.46	3.0	1.5
Oil	6.39	3.0	1.5

* Corresponds to 5.36¢/kWh at the building boundary.

Table 2. Appliance lifetimes (in years).

Central heater	20
Water heater	10
Ranges and ovens	14
Dryers (electric)	14*
Central air conditioners	14
Room air conditioners	10
Refrigerator	15
Freezer	20

* 11 for gas dryers.

Source: U.S. Department of Energy.[9]

Cost versus efficiency data were provided by Arthur D. Little, Inc. (ADL).[3] ADL began with a base case appliance which reflected 1978 sales-weighted energy efficiency data taken from an industry survey (DOE Form CS 179). Using engineering analysis and computer simulations, ADL estimated the efficiency improvements resulting from implementation of various design options. For the analysis, the design options considered were limited to those based on available technology, defined as those technologies presently implemented in units available in the marketplace, at least in limited quantities. Only those design options were considered which were represented by existing test procedures.

Figures 1 and 2 illustrate cost versus efficiency curves for automatic defrost top-mount refrigerators and split system central air conditioners, respectively. Also shown are the design options chosen for analysis. Points on the curves are generated by implementing combinations of design options. In Figure 2, the same design options (1, 2, 3) are used for each data point. In cases of this type, the design options were carried out to varying degrees. These design options are described in detail for each product type in Technical Support Document (TSD) No. 5, Engineering Analysis.[4]

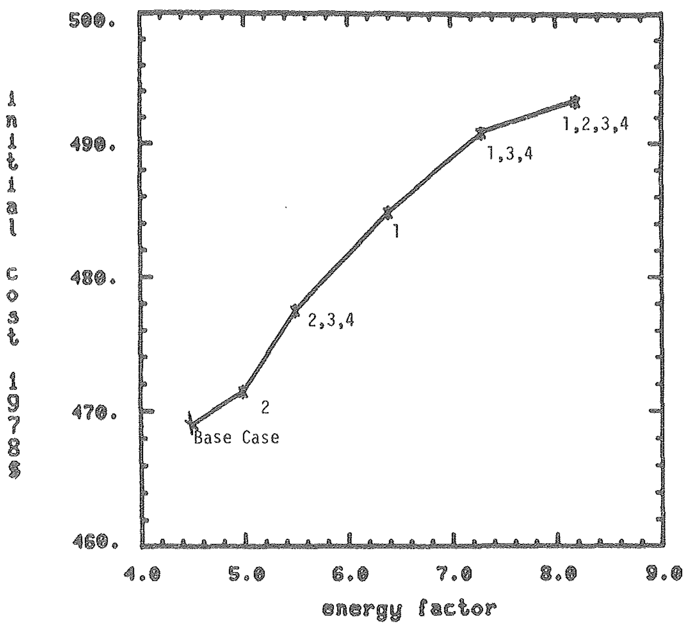

Fig. 1. Cost versus efficiency for automatic defrost, top-mount refrigerator. The design options are (1) foam insulation substitution; (2) high-efficiency compressor substitution; (3) double-door gasket in freezer; (4) place evaporator fan motor outside of cold space. (XBL 8010-12522)

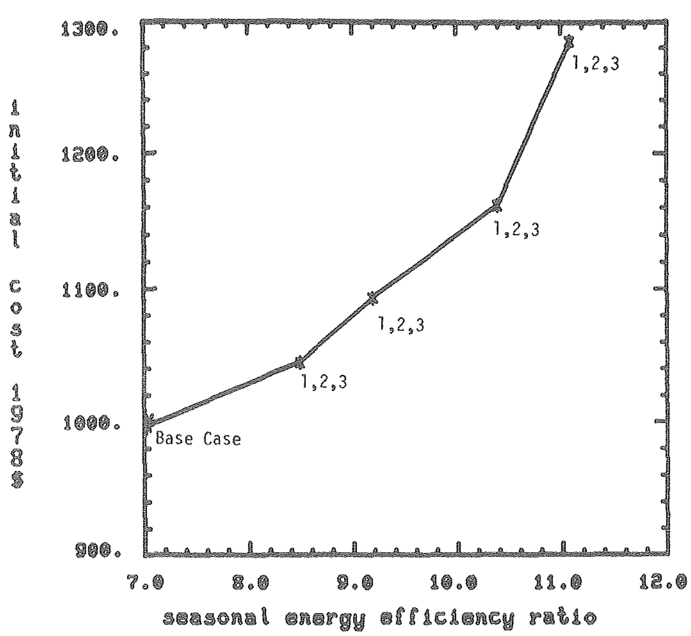

Fig. 2. Cost versus efficiency for central air conditioner, split-system. The design options are (1) increased condensor and evaporator heat-exchanger surface area; (2) decreased compressor size; and (3) different fan motor. In cases where the same design options are used for more than one data point, these options have been employed to varying degrees. For details see Reference 4. (XBL 8010-12523)

Average annual energy consumption per unit is composed of two factors, an energy (or efficiency) factor and a usage factor. In general for each appliance model:

$$\text{annual energy use per unit} \propto \frac{\text{usage factor}}{\text{energy factor}}$$

In some cases the annual energy consumption in the ADL data base is significantly different from that found by Oak Ridge National Laboratory (ORNL).[5] Table 3 compares values obtained from ORNL with data provided by ADL for the base case appliance.[6] The ORNL values were used in the LCC analysis because the ORNL estimates were from a broader, more complete data base.

The life-cycle cost analysis was performed on a national basis for all the covered products. In addition, the analysis was performed on a regional basis for the three products whose usage is highly dependent on weather: furnaces, central air conditioners, and room air conditioners. The regions, shown in Figure 3, were defined by DOE as follows:

Table 3. Annual energy use per unit.*

Consumer product	Fuel or energy source	ORNL†	ADL‡	ORNL/ ADL
Refrigerator	Electric	1740	1548.0	1.12
Freezer	Electric	1642.6	1170.5	1.40
Dryer	Electric	1114.8	1066.6	1.04
Dryer	Gas	7.0	4.2	1.67
Water heater	Electric	4599	6620	.69
Water heater	Gas	25.0	36.6	.68
Ranges/ovens	Electric	1246.1	407.0	3.06
Ranges/ovens	Gas	9.6	4.4	2.18
Air conditioners (room)§	Electric	1708.7	1238.2	1.38
Air conditioners (central)	Electric	3106.1	4373.7	.71
Central space heat	Gas	88.7	126.2	.70
Central space heat	Oil	141.8	118.7	1.19

* Energy use is in kWh for electric appliances and in 10^6 Btu for gas and oil appliances, respectively.

† 1977 values, weighted by housing units.

‡ A.D. Little values, weighted by 1978 sales.

§ 1708.7 kWh is the annual energy use per household. To obtain annual energy use per unit for room air conditioners, divide 1708.7 kWh by 1.45, the number of room air conditioners per household (among households having room air conditioners).

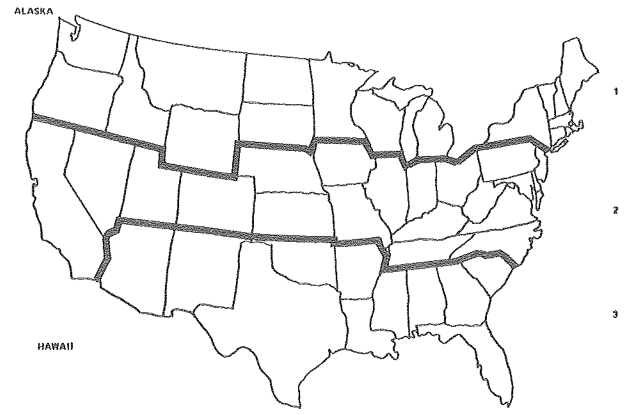

Fig. 3. Heating and cooling regions of the United States for purposes of analysis of appliance efficiency standards. Source: DOE (1980). (XBL 8010-12524)

Region 1. > 2.500 heating-load hours

≤ 600 cooling-load hours

Region 2. > 1,750 ≤ 2,500 heating-load hours

> 600 ≤ 1,200 cooling-load hours

Region 3. ≤ 1,750 heating-load hours

> 1,200 cooling-load hours

RESULTS

Equations 2 and 3 have been used to calculate consumer life-costs for 32 classes of eight products covered by DOE's proposed regulation.[7] Figure 4, an LCC curve for an automatic defrost top-mount refrigerator/freezer is typical of most appliances studied. The LCC decreases continuously with increasing energy efficiency, i.e., the energy cost savings derived from the use of more efficient models of this class of refrigerator/freezer more than compensate for the extra initial cost of these models, when any model is compared to one of lower efficiency.

Figure 5, for a split-system central air conditioner, is illustrative of classes of appliances in which the minimum life-cycle cost does not occur for the highest efficiency model. There are four other cases [all room air conditioners (RAC), except those of capacity greater than 20,000 Btu/h, and gas clothes dryers] where the minimum in LCC occurs before the highest efficiency model. For appliances of this type, consumers do not benefit most by purchasing the highest efficiency model available.

Table 4 compares the proposed 1985 standards, the sales weighted energy factor (SWEF) in 1978, and the projected 1985 SWEF (in the absence of standards). The projected 1985 SWEF (baseline efficiency) was obtained by multiplying the 1978 SWEF by a factor equal to the improvement in energy efficiency predicted to occur between 1978 and 1985 (obtained from the ORNL residential energy use model).

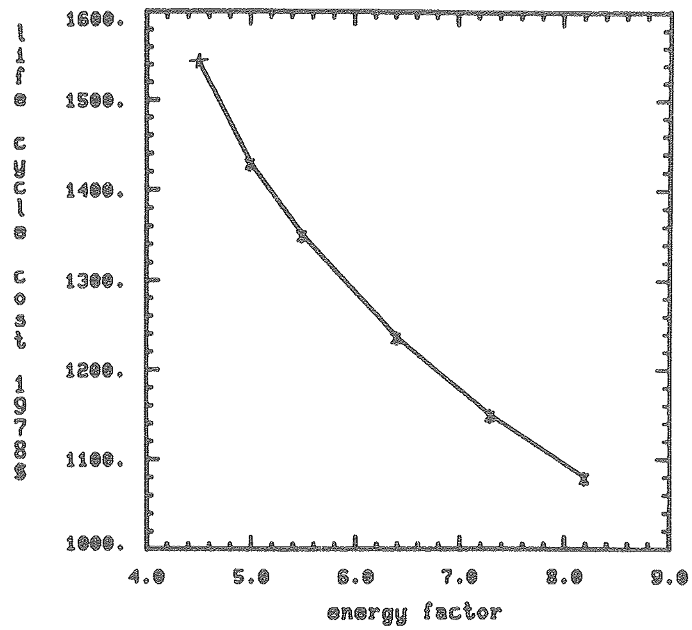

Fig. 4. Life-cycle costs of refrigerators (automatic defrost, top mount), evaluated at a 5% real discount rate and at DOE's high-energy price case (2.5% per year real electricity price escalation rate). (XBL 8010-12525)

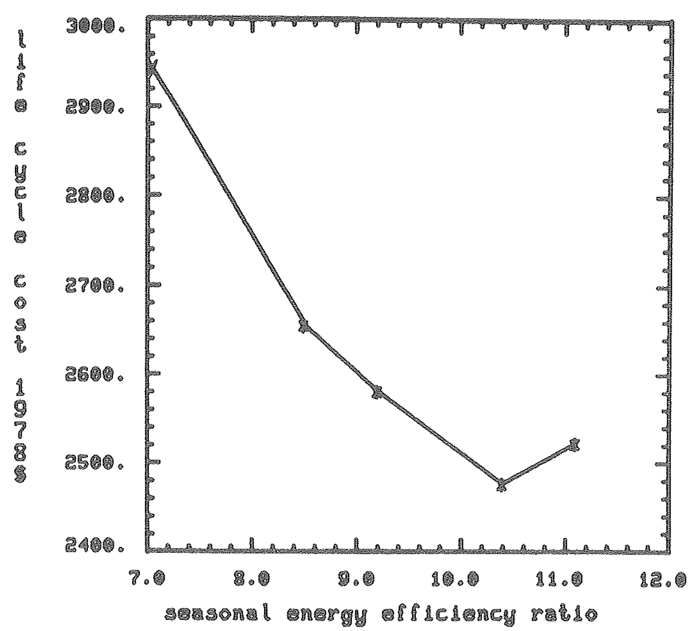

Fig. 5. Life-cycle costs of split-system, 30,000 Btu/h, central air conditioners evaluated at a 5% real discount rate and at DOE's high-energy price case (2.5% per year real electricity price escalation rate). (XBL 8010-12526)

Table 4. Compilation of proposed 1985 standards and base case energy efficiencies.

Product	DOE's Proposed 1985 Standard	SWEF (1978)	SWEF* (1985)
CAC			
Split	11.0	7.02	7.63
Single	10.5	6.90	7.50
RAC			
< 6,000 Btu	8.4	6.17	6.65
6,000 Btu to 20,000 Btu	9.5	7.25	7.80
>20,000 Btu	8.4	6.74	7.25
Through wall and reverse cycle	9.0	6.55	7.05
Furnaces			
Gas, indoor forced air	81	64.6	69.8
Gas, boiler	79	65.1	70.4
Gas, outdoor horizontal, nonweatherized	74	56.0	60.6
Gas, outdoor weatherized	76	68.0	73.4
Oil, forced indoor	80	75.25	79.6
Oil, boiler	82	75.8	80.2
Oil, outdoor forced air	78		
Water Heaters			
Gas	63	48.2	51.3
Electric	93	80.67	84.3
Clothes Dryers			
Electric standard	3.0	2.6	2.70
Electric compact, 120V	2.85	2.63	2.73
Electric compact, 240V	2.54	2.35	2.44
Gas	2.60	2.38	2.44
Ranges and Ovens			
Gas cook top	45.0	30.8	36.2
Gas oven	6.4	4.6	5.4
Gas oven, self-cleaning	6.0	4.8	5.6
Electric cook top	79	75.0	77.2
Electric oven	14.1	13.0	13.4
Electric oven, self-cleaning	13.6	12.6	13.0
Refrigerators			
Refrigerator, manual	17.2	7.11	8.3
Part. auto	11.6	5.35	6.24
Auto-top mount	8.2	4.73	5.52
Auto side-by-side	7.0	5.01	5.85
Auto side-by-side TTD	6.3	5.03	5.87
Freezers			
Manual chest	18.7	11.29	12.92
Manual upright	16.3	9.21	10.54
Auto, upright	9.6	6.36	7.28

* The projected 1985 sales weighted energy factor (SWEF) is obtained by multiplying the 1978 SWEF by the improvement in efficiency predicted by the ORNL residential energy use model.

SUMMARY AND CONCLUSION

On a national basis, the proposed 1985 standards are cost-effective with respect to the energy efficiency levels projected to occur in the absence of standards for all classes of products. The proposed 1985 standard produces higher life-cycle cost savings than a standard at a lower energy efficiency except for two cases, split-system central air conditioners and room air conditioners of 6,000 to 20,000 Btu/h capacity. However, in both cases, the life-cycle cost reduction achieved by the proposed standard is only slightly less (<1%) than that achieved at any lower trial level. In our view, this small increase in life-cycle cost for these two cases is justified by the resulting greater energy savings to the nation.

In two cases, the proposed efficiency standard is below the trial level where the life-cycle cost minimum occurs. These are (1) room air conditioners of capacity less than 6,000 Btu/h, where the proposed standard is at an energy efficiency ratio (EER)* of 8.4 and the LCC minimum is at 9.1, and (2) single-package central air conditioners, where the proposed standard is set at a seasonal energy efficiency rate (SEER) of 10.5 and the LCC minimum is at 10.7.

Data were not available to analyze the life-cycle costs of many advanced-technology options (including product redesigns) required to achieve higher levels of energy efficiency for most of the consumer products. As a result, no conclusions can be reached about the potential of many advanced-technology options for reducing life-cycle cost to the consumer. Advanced technologies that should be analyzed in the future include heat pump water heaters, integrated space and water heating appliances, and condensing furnaces.[8]

Simple payback periods are considerably less than the equipment service lifetime for all products evaluated (see Table 5). For the proposed standards, they range from several months for refrigerators and freezers to a maximum of 5.3 years for split-system central air conditioners. For most products, the payback period is less than 2 years.

The regional life-cycle cost analysis indicates that the distribution of costs and benefits from the proposed national standards varies significantly among the different regions for room and central air conditioners and for furnaces. For the product class with greatest variation, the split-system central air conditioner, the change in consumer life-cycle cost at the proposed standard ranges from an increase of $119 (8% of total LCC) in Region 1 to a decrease of $552 (15% of total LCC) in Region 3. For room air conditioners of capacity 6,000 to 20,000 Btu/h, the change in consumer life-cycle cost at the proposed standard ranges from an increase of 15 dollars (4%) in Region 1 to a decrease of 85 dollars in Region III.

* EER = the maximum rate at which heat is removed (in Btu/h) divided by the electric power input in watts.

Table 5. Appliance simple payback periods for national average energy use.

Product type	Payback period (years)
Refrigerator/freezers	0.5-0.8
Freezers	0.2-0.4
Clothes dryers	2.3-4.2
Water heaters	
Electric	0.7
Gas	0.9
Room air conditioners	1.5-4.5
Ranges and ovens	1.2-3.1
Central air conditioners	
Split-system	5.3
Single package	2.3
Furnaces	0.2-2.6

Simple payback periods are longer in Region 1 than those obtained in the national analysis for all classes of air conditioners. For two cases, the simple payback periods are greater than the average appliance lifetime.* These are split-system central air conditioners (22.1 years) and room air conditioners of capacity 6,000 to 20,000 Btu/h (15.2 years).

One potential method of redressing the inter-regional inequity in costs and benefits for air conditioners is to promulgate regional efficiency standards. This is a subject of continuing research, and no firm conclusions have been reached as yet.

*Simple payback period is greater than the appliance lifetime whenever there is an increase in life-cycle cost.

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A COMPARISON OF REGIONAL AND NATIONAL ENERGY EFFICIENCY STANDARDS FOR ROOM AND CENTRAL AIR CONDITIONERS*

I. Turiel

INTRODUCTION

In accordance with the Energy Policy and Conservation Act (Public Law 94-163), as amended by the National Energy Conservation Policy Act (Public Law 95-619), the Department of Energy (DOE) has proposed energy efficiency standards for eight consumer products.[1] One of the criteria on which these standards are based is the life-cycle cost (LCC) of owning and operating an appliance over its lifetime. In the long run the consumer benefits from the purchase of a product with the lowest life-cycle cost.

Because energy prices and appliance utilization patterns vary regionally, for some appliances,

* This work was supported by the Standards Branch Consumer Products Division, Office of Buildings and Community Systems, U.S. Department of Energy under Contract No. 7405-ENG-48.

the imposition of national energy efficiency standards may result in an inequitable distribution of costs and benefits among various climatic regions. Since variations in energy consumption are most significant in space-heating and cooling products, this analysis of costs and benefits will focus on central and room air conditioners. Central space-heating equipment has not been analyzed in this comparative study since the total life-cycle cost (LCC) curve for all classes of space-heating equipment does not reach a true minimum in any climatic region (i.e., all presently available energy conservation measures are cost-effective in all regions).

Any inequity in distribution of consumer costs and benefits could be alleviated by promulgating efficiency standards on a regional basis. Three regions were selected along state boundaries for use in the regional analysis of the proposed standards for central and room air conditioners. The regions are shown in Figure 1 and are defined as follows:

Region 1. $> 2{,}500$ heating-load hours

$\leqslant 600$ cooling-load hours

Region 2. $> 1{,}750 \leqslant 2{,}500$ heating-load hours

$> 600 \leqslant 1{,}200$ cooling-load hours

Region 3. $\leqslant 1{,}750$ heating-load hours

$> 1{,}200$ cooling-load hours

The standards could be chosen so as to separately minimize life-cycle costs in each of the three regions, thereby eliminating any potential inequities. Figures 2 and 3 show LCC curves[2] for one class (half of yearly sales) of room air conditioners and one class (85% of yearly sales) of central air conditioners. In both cases, consumers in Region 1 would suffer an increase in LCC if they purchased air conditioners in 1986 whose efficiency was equal

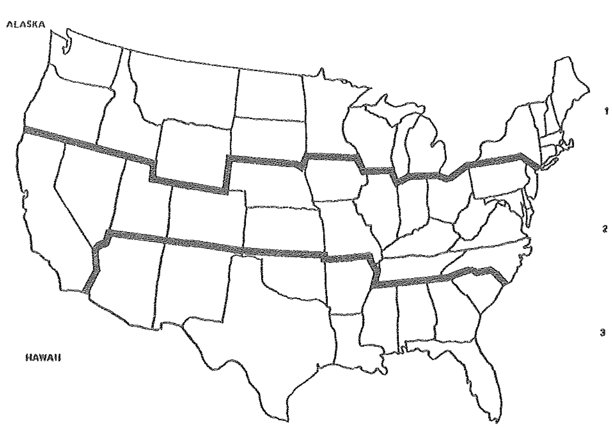

Fig. 1. Heating and cooling regions of the United States for purposes of analysis of appliance efficiency standards. Source: DOE (1980) (XBL 8010-12524)

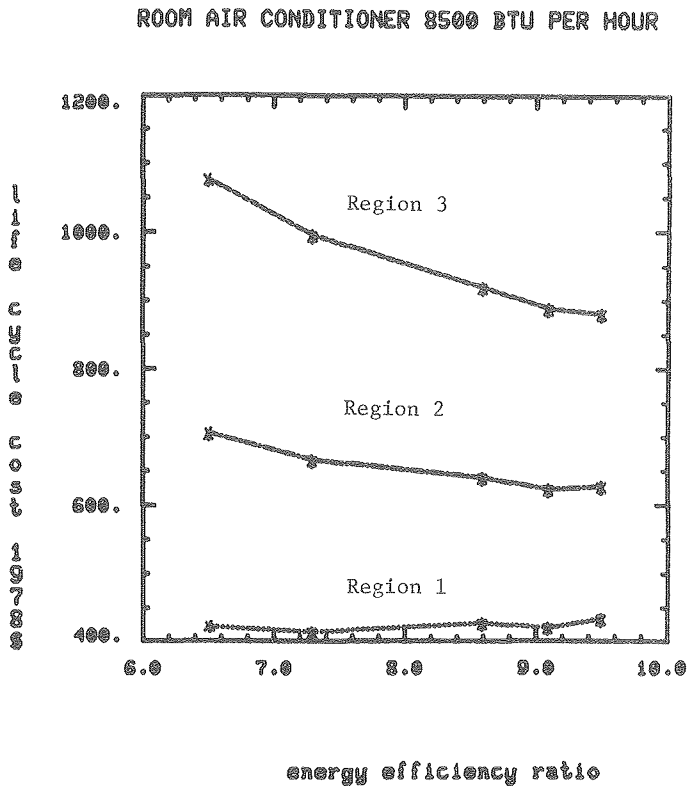

Fig. 2. Life-cycle cost as a function of energy efficiency for a room air conditioner with 8500 Btu/H capacity. (XBL 8010-12519)

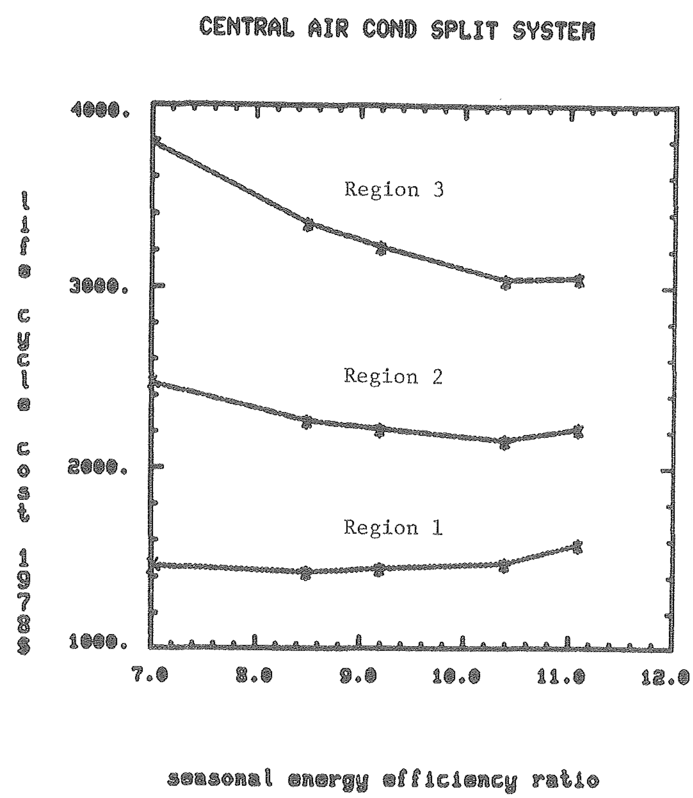

Fig. 3. Life-cycle cost as a function of energy efficiency for a split system central air conditioner with 30,000 Btu/H capacity. (XBL 8010-12520)

to the proposed 1986 standard rather than the projected 1986 energy efficiency in the absence of standards.

A study to determine the effect of regional and national energy efficiency standards on national energy consumption and total cost (appliance first cost plus operating cost) was carried out for central and room air conditioners. A discussion of the results obtained will follow a description of the methodology and assumptions.

METHODS AND ASSUMPTIONS

In order to evaluate the national economic and energy-use impacts of alternative standards, a simplified model of new appliance energy consumption was developed. In this energy use model, energy consumption of new appliances being purchased from 1982-2005 was calculated. National energy consumption is a function of appliance shipments, lifetime, energy efficiency, and annual energy use per base case (1978) unit.

Operating costs were determined by computing the product of energy use and fuel cost. The initial cost of new appliances was assumed to be paid in the year of purchase. A discount rate of 10%, real, was applied to fuel cost and appliance first cost to obtain the present value of each. High fuel price (2.5% real fuel price escalation rate for electricity) and low fuel price (1% escalation rate) scenarios were analyzed to bound the possible outcomes of alternative standards. The national average electricity price for the high and low fuel price scenarios in 1982 were \$0.0498/kWh and \$0.483/kWh respectively (in 1978 dollars).

Average appliance lifetimes were taken to be 10 years for room air conditioners (RAC's) and 14 years for central air conditioners (CAC's). In this simplified Energy Use Model, all appliances are assumed to have average lifetimes. For example, of 2.34 million CAC's purchased in 1982, all of them would still be in operation in 1995, and none of them would be in operation in 1996 or later. Appliance shipments were taken from the Oak Ridge National Laboratory (ORNL) Residential Energy Use Model predictions.[3]

As in the ORNL model, the relationships between initial appliance cost and energy efficiency are modeled with three-parameter equations as shown below:

$$\frac{C}{C_o} = \frac{B_3 + 1}{\left[\dfrac{E/E_o - B_1}{1 - B_1}\right]^{1/B_2}} - B_3$$

where

$\frac{C}{C_o}$ = initial cost relative to 1978 base case equipment cost

E = annual energy use (kWh/yr)

E_o = annual energy use for 1978 base case unit

B_1, B_2, B_3 = constants

The three parameters of the curves for each type of consumer product are given in Table 1. These parameters, describing the cost versus efficiency tradeoffs, are derived from engineering/economic analyses performed by Arthur D. Little, Inc. (ADL).[4] For central air conditioners, the energy consumption in any region, ENC(j), is given by the following equation:

$$ENC(j) = .71 \times ENCR(j) \times \left[\frac{6.87}{SEER\ (j)}\right]$$

where

ENCR(j) = base case energy consumption in region j

SEER(j) = seasonal energy efficiency ratio in region j.

The 0.71 in this equation normalizes the ADL energy use estimates to the ORNL values. The 6.87 in the equation is the SEER of an average central air conditioner sold in the base year.[5]

Regional energy use was obtained by weighting national energy use by a fraction equal to regional cooling load hours divided by national average cooling hours.[6,7]

In order to determine whether to establish a national standard or a regional standard for each product type, it is necessary to consider the following:

1. The reduction in fuel cost due to the implementation of a regional rather than a national standard.

2. The increase in equipment price due to the implementation of a regional rather than a national standard.

3. The inequity in distribution of costs and benefits to consumers in different regions under national standards.

4. The increase in first cost, certification, and enforcement costs due to the implementation of a regional rather than a national standard.

5. The energy savings achieved by each standard.

Table 1. Coefficients for cost versus energy efficiency curves for air conditioners.

	Year	B_1	B_2	B_3
Room air conditioners	(1982-1985)	.62	11.0	-.01
	(1986-2005)	.35	1.0	-.84
Central air conditioners	(1982-1985)	.57	5.7	-.40
	(1986-2005)	.46	1.05	-.88

The difference between items (1) and (2) is the net present benefit to all consumers in the nation purchasing the product of interest in the period 1982-2005. If this quantity is positive, then it should be compared to item (4). If (1)-(2) is greater than (4), then regional standards produce greater economic benefits to the nation than the proposed national standards.

RESULTS AND CONCLUSIONS

For central air conditioners, the potential energy use reduction resulting from promulgation of regional standards as compared to national standards is quite small (<5% increase). This result is due to the fact that the proposed national energy efficiency standards for central air conditioners (11.0 for split-system and 10.5 for single package) are almost as high as the maximum efficiencies (11.1) analyzed in the ADL cost book.[4] The potential energy savings derived from regional standards is much larger for room air conditioners.

As can be seen from Table 2, if the Regional Standard Scenario (8.7, 11.1, 11.1) is compared to the base case, 1.6 quads of primary energy are saved rather than only .8 quads when the Proposed National Standards are compared to the Base Case. While it is true that tighter National Standards (10.9) can produce the same energy savings (1.8 quads) as regional standards, the total cost to the nation is higher by 80 million dollars (for both the low and high fuel price cases) and the inequity in distribution of consumer costs and benefits among the three regions is significantly worsened.

Table 2. Total cost* and energy use for room air conditioner use in three DOE regions.

Scenario	Energy use‡	Region 1	Region 2	Region 3	Entire U.S.
Base case	6.43	1.834	7.175	6.917	19.594
Proposed national standards (7.44,9.0)	5.64	1.791	6.656	6.377	14.824
Tighter national standards† (7.44 10.9)	4.84	1.843	6.439	5.976	14.258
Regional standards (8.7,11.1, 11.1)	4.84	1.789	6.435	5.953	14.177

* Total cost includes first cost and operating cost and is expressed in billions of 1978 dollars.

† These tighter national standards are equivalent to the regional standards in energy use.

‡ Quads of primary energy.

There is a net present benefit, (1)-(2) > 0, for each of the three regions when national standards are instituted as compared to the no standards case. The net present benefit increases from 40 million dollars for Region 1 to approximately 530 million dollars for each of Regions 2 and 3. When Tighter National Standards (10.9) are compared to the Base Case, the net present benefit is negative in Region 1 by approximately 10 million dollars. Therefore, reducing national energy use to the same extent as the Regional Standards (8.7, 11.1, 11.1) by instituting Tighter National Standards (10.9), results in a net present cost, (1)-(2) < 0, in Region 1 of 10 million dollars whereas regional standards result in a net present benefit of 45 million dollars in Region 1. For the nation as a whole, the net present value is 80 million dollars greater for regional than for the equivalent national standards.

As stated earlier, it is necessary to estimate item (4), the increase in first cost, certification, and enforcement costs, and to compare the sum to the net present benefit of regional standards. If (4) is less than (1)-(2), (80 million dollars) then an economic argument for regional standards can be made. In this report, we do not attempt to quantify item (4) but only mention that increased first costs would result if manufacturers had to increase the number of product lines and models to meet standards in all capacity ranges for both regions (1 and regions 2 and 3, combined). In addition, distribution and storage costs may increase. We recommend that the potential additional costs (outlined above) of instituting regional standards be more precisely quantified by DOE. Table 3 summarizes the comparisons of various alternative standard scenarios to the base case (no standards). National net present benefit and national energy savings are shown for three alternatives and for a high and low fuel price scenario. In the low fuel price scenario, the base case energy consumption is greater than for the high fuel price scenario as consumers purchase less efficient (and lower cost) air conditioners when fuel prices are lower. The national energy savings for regional standards as compared to the

Table 3. National net present benefit and energy savings of alternative standards (relative to base case) room air conditioners.

Scenario	Net present benefit (billions 1978 $) high	Net present benefit (billions 1978 $) low	Energy savings (in quads) high	Energy savings (in quads) low
Proposed national standards (7.44, 9.0)	4.77	1.28	.8	1.33
Regional standards (8.7,11.1,11.1)	5.42	1.69	1.6	2.13
Equivalent national standards (7.44, 10.9)	5.34	1.60	1.6	2.13

national standards is .80 quads (an increase from 1.33 to 2.13 quads).

Summarizing, for room air conditioners, regional standards (in the high and low fuel price scenarios) increase national energy savings by .80 quads relative to the base case and increase the net present benefit by 650 million dollars or 410 million dollars for the high and low fuel price scenarios respectively.

Two matters requiring additional attention are the expected time of availability for room air conditioners with higher efficiency (an average EER of 11.0 across all classes) and the magnitude of additional first cost, if any, caused by promulgation of regional standards rather than national standards.

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NEW DATA APPLICABLE TO THE ORNL RESIDENTIAL ENERGY DEMAND MODEL*

H. Herring

INTRODUCTION

The Oak Ridge National Laboratory (ORNL) Residential Energy Model has been widely used to forecast energy demand and to evaluate the impacts of federal energy conservation policies. The model has been criticized as inadequate in a number of areas. The objective of this work has been to make selected improvements in the model as a first step in a longer-term effort to substantially upgrade its accuracy, reliability, and sensitivity to a range of realistic input assumptions.

A model is only as good as its input data, and much of the input data to the model is poorly documented. Thus, one of our major objectives has been to improve the data inputs. These are major inputs to the model.

1. Appliance saturations by house type, both in the existing housing stock and in new homes.
2. The annual energy use of stock and new appliances.
3. The average lifetime of appliances, and hence the rate at which appliances are retired and are replaced by new ones.
4. The energy efficiency of stock and new applicances.
5. The price of fuels and their expected escalation rates.
6. The price of new appliances.
7. The thermal integrity of stock and new buildings.

ACCOMPLISHMENTS DURING FY 1980

Retirement Rates for Appliances

An important input to the ORNL Model is the rate of retirement of old appliances. Currently an exponential equation of the form

$$YKAP = 1 - e^{(-1/TEQ)}$$

is used, where TEQ is the average life of the appliance, and YKAP is the fraction retired each year. Thus the fraction surviving after n years is $(1\text{-}YKAP)^n$. Figures 1 and 2 show the retirement

* This work is supported by the Systems Analysis Division, Office of Buildings and Community Systems, U.S. Department of Energy under Contract No. 7405-ENG-48.

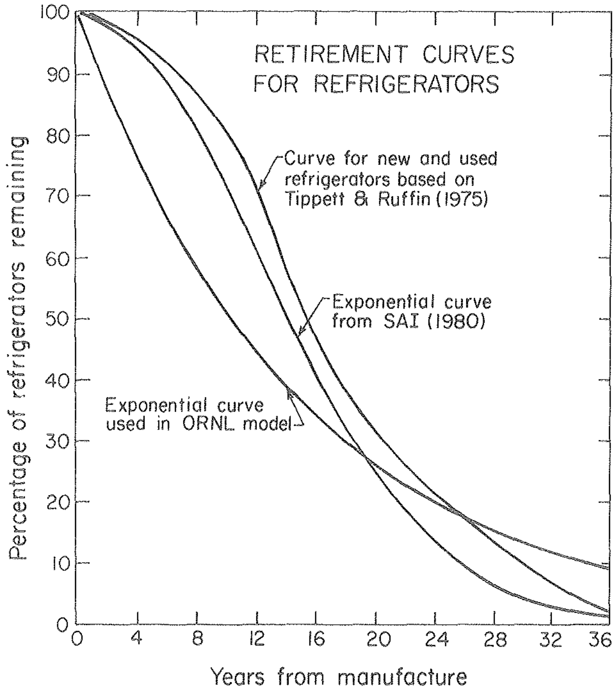

Fig. 1. Retirement curves for refrigerators. (XBL 8012-2467)

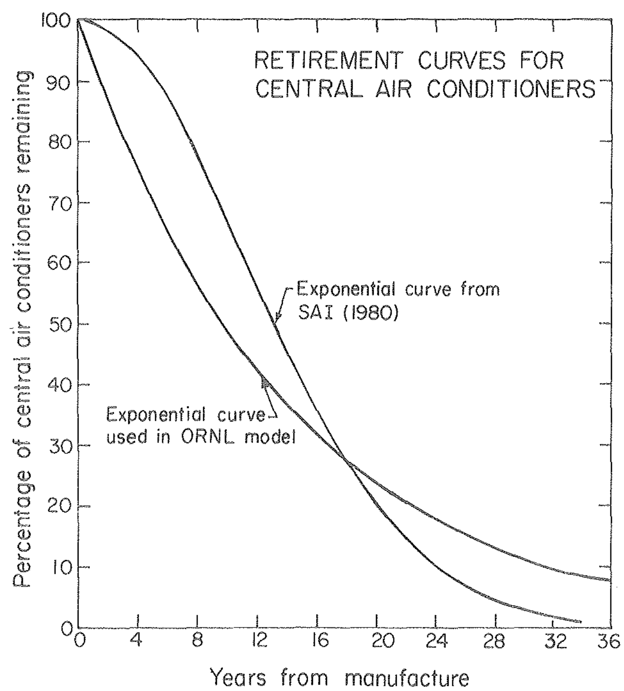

Fig. 2. Retirement curves for central air conditioners. (XBL 8012-2468)

rates for refrigerators and central air conditioners. The curve using the ORNL equation leads to a rapid decline in the early years of the appliance's life, and a slow decline in the later years.

Using the above exponential equation to specify retirement rates in the ORNL Model reduces energy demand growth more rapidly than should occur, as old, less efficient appliances are quickly replaced by new more efficient ones. A market survey in 1975 by Ruffin and Tippett of 11,696 households throughout the United States provided estimates of the service life expectancy of major appliances having one owner.[1] The data are for new and used appliances. To combine these data into the total life expectancy under all owners (as appliances are resold), one needs to know the rate at which appliances are sold according to their age. This was determined for refrigerators by analyzing the responses to a Market Facts, Inc. survey on appliance ownership and use.[2]

Figure 1 shows the retirement rates for refrigerators. The top curve is based on the work of Ruffin and Tippett, and combines their data for retirement rates for new and used refrigerators. This curve shows refrigerators have an average lifetime of 17.2 years. From their data on the average lifetime of new refrigerators (15.2 years) and of used refrigerators (7.4 years), one can calculate a resale rate of 26%.

The other two curves in Figure 1 are exponential curves based on a refrigerator lifetime of 15 years, which is currently used in the ORNL model. An alternative functional relationship can be used to better fit observed data:

$$N = N_o \cdot e^{(-0.693\ t^2/T^2)}$$

where N is number of appliances remaining at t years, N_o is original number at t = 0, and T represents the time at which half of the original appliances have stopped operating. T is related to the average lifetime of all appliances, t_{ave}, by

$$t_{ave} = \frac{T}{2} \cdot (\pi/\log 2)^{1/2} = 1.064\ T$$

This curve is fairly close to the modified Ruffin and Tippett curve and diverges most from it late in the appliance's life, when the numbers of refrigerators remaining in stock are small. Use of this curve, rather than the current ORNL curve, means that the energy consumed by appliances, is assumed to be greater in the near future as fewer older appliances have retired, and corresponds closer to empirical data than the current ORNL exponential equation.

Figure 2 shows retirement curves for central air conditioners. Unfortunately there are no market survey data to provide information on retirement or resale rates, and the exponential curves shown are based on a 14-year lifetime, which is currently used in the ORNL Model.

Market surveys provide useful information on appliances ownership, use, and lifetimes. The National Interim Energy Consumption Survey (NIECS), conducted in 1977 and 1978, was particularly useful as actual fuel use was measured for 4081 surveyed households. By cross-tabulating fuel use by house type, house age, appliance ownership, central heating system, and other factors, much valuable information can be extracted which is directly relevant to the ORNL inputs

Total Residential Energy Use

Table 1 and 2 shows the energy consumption by fuel type. The houses in the survey have a wide range of fuel consumption rates, but the mean values for all three "fuels" (electricity, natural gas, and fuel oil/kerosene) are approximately equal. If the mean energy consumption is multiplied by the average fuel saturation, an average annual household energy consumption can be obtained, which is 213.8 million Btu of primary energy. This figure is 5.6% greater than that used in the ORNL model, and provides good support for this portion of the ORNL data base.

Household energy consumption can be cross-tabulated with house type, age, and region, but a good indicator of differing energy use is therms of energy consumed/ft^2 of household area/yr. Data from the ORNL Building Energy Use Data Book and other sources (ORNL/CON-28) give the average floor area of households by housing type and age.[3,4] Table 3 shows that the floor area for all house types has increased; for single-family homes the increase is by 21%; multifamily homes (which includes attached single family homes and apartments) increased by 6%; and mobile homes by 22%.

Table 4 shows energy consumption in terms of therms/ft^2/year. Although in absolute terms new homes use more energy than stock homes (built before 1976), new homes use less than older homes in terms of therms/ft^2/yr. The improvement in energy use varies according to whether electricity is measured in terms of primary energy use (11,500 Btu per kWh) or in terms of building boundary use (3,400 Btu/kWh). Overall electricity consumption has increased by 21% with the greatest increase being in multifamily homes with more than a 50% increase, while single-family homes have had a 32% increase; however, mobile homes show a 42% decrease in electricity use.

In primary energy terms, the total household energy use/ft^2 is greater than if it were measured

Table 1. Energy consumption in the residential sector by fuel type. (10^6 Btu Primary Energy)

	Electricity	Natural Gas	Fuel Oil/ Kerosene
Minimum	1.09	0.2	3.89
Maximum	832.2	599.2	442.3
Range	831.1	599.0	438.4
Median	85.8	111.9	113.2
Mean	111.8	119.0	124.4
Saturation (%)	100	63.1	21.6

Table 2. Average household energy consumption. (10^6 Btu)

Electricity	111.8
Natural gas	75.1
Fuel oil	26.9
Total	213.8

Table 3. Floor area of households (ft^2).

	Stock	New Homes
Single-family	1380	1672
Multifamily	845	895
Mobile homes	780	952
All	1194	1356

Table 4. Energy consumption per ft^2 primary energy units: therms/ft^2/year.

	Electricity	Natural Gas	Fuel Oil/ Kerosene	All Fuels
Stock				
Single-family	0.856	0.970	0.886	1.661
Multifamily	0.843	0.988	1.685	1.950
Mobile homes	1.678	1.777	0.771	2.194
All stock	0.888	0.973	1.029	1.736
New Homes				
Single-family	1.132	1.022	0.666	1.517
Multifamily	1.328	1.166	0.0	1.888
Mobile homes	0.977	0.899	0.634	1.601
All new homes	1.074	1.039	0.727	1.557

in building boundary units. Table 5 shows how new homes compare to stock homes in energy use. Mobile homes show the greatest decrease in energy use/ft^2, with single-family homes second and multi-family homes last. Energy use at the building boundary has decreased much more rapidly than primary energy. The reason for this is the switch away from natural gas and fuel oil for central space heating towards electricity.

Table 6 shows estimates of central space heating (CSH) fuel saturations by house type derived from the NIECS survey tape. There has been a dramatic switch from natural gas (55.4% of all CSH systems in older houses) to electricity 86.3% of all new CSH systems in 1978). The use of fuel oil has declined in all homes (from nearly 25% of the CSH systems), while electricity has almost doubled; it now provides a third of the fuel for CSH systems in new homes. The figures in parentheses are the values currently used in the ORNL model; they underestimate electricity CHS systems and overestimate fuel oil systems in older homes. The reverse is true for new homes, particularly for mobile homes where gas CSH systems are vastly underestimated.

Table 5. Comparison of new homes to stock energy use (therms/ft^2/yr).

	Primary Energy	Building Boundary Energy
Single-family	0.913	0.681
Multifamily	0.968	0.703
Mobile homes	0.730	0.554
All homes	0.897	0.721

Table 7 shows the saturations of fuels, for all end uses in homes.

Electricity use is practically universal in the United States: only one of the 4081 homes surveyed had no electricity. Gas is found less frequently in new single- and multifamily homes, but most often in mobile homes where it is the most common source of heating. Fuel oil has declined rapidly in popularity among new homes and was not used at all in the 46 new multifamily homes surveyed.

The fact that energy used/ft^2 has not declined as much as might be expected due to more stringent building insulation standards (for new homes than for old homes) probably results from the use of higher levels of space conditioning and a greater saturation of energy consuming appliances.

Mobile homes show the greatest decrease in energy use/ft^2, and are now about equal in energy use to single-family homes. This could be due to increased use of insulation measures compared to other housing types, and because of the shift away from electricity to natural gas.

Further analysis of the NIECS data will show fuel use and type for water heating and for cooking; regional fuel variations; saturations of appliances; and fuel use variations according to the presence (or absence of insulation).

Table 6. Central space heating fuel saturations by house type (%).

	Electricity		Natural Gas		Fuel Oil/ Kerosene		Other	
Stock								
Mobile homes	17.5	(12.3)	64.7	(39.5)	15.7	(22.2)	2.1	(25.9)
Single-family	16.8	(7.7)	60.8	(62.4)	20.7	(25.7)	1.7	(4.2)
Multifamily	17.1	(12.6)	55.4	(51.0)	26.2	(35.2)	1.3	(1.2)
All stock	16.9	(9.4)	59.4	(57.8)	22.0	(28.4)	1.7	(4.4)
New Homes								
Single-family	36.3	(42.1)	48.8	(48.6)	13.6	(6.9)	1.4	(2.3)
Multifamily (1978)	86.3	(58.0)	10.5	(33.4)	2.8	(8.0)	0.3	(6.0)
Multifamily (1976)	24.9	n.a.†	58.0	n.a.†	15.5	n.a.†	1.7	n.a.†
Mobile homes	10.9	(56.8)	69.1	(26.0)	18.0	(5.1)	1.9	(12.1)
All new homes	33.3	(48.1)	51.1	(42.5)	14.2	(7.2)	1.3	(2.2)

* Figures in brackets are those for 1977 CSH saturations, units, and existing units, from ORNL model.

† n.a. = not available.

Table 7. Saturation of fuels by house type (%).

	Electricity	Natural Gas	Fuel Oil/ Kerosene
Stock			
Single-family	100	62.5	22.4
Multifamily	100	77.1	20.5
Mobile homes	100	24.8	29.1
All stock	100	64.3	21.6
New Homes			
Single-family	100	32.0	8.7
Multifamily	100	48.0	0.0
Mobile homes	100	64.0	7.7
All new homes	100	42.0	6.4

Table 8. Number of cases in survey: house types.

	Stock	%	New Homes	%
Single-family	2568	66.3	114	58.2
Multifamily	1072	27.7	46	23.5
Mobile homes	234	6.0	36	18.3
Missing cases	11			
Total cases	4081			

PLANNED ACTIVITIES FOR FY 1981

The work will continue to analyze all data applicable to the projection of residential energy demand, in an effort to improve the quality of the ORNL energy demand model. The main emphases of the work will be on the following tasks:

- Continued use of the NIECS data base, and disaggregation of energy use among space conditioning and appliance uses.
- Gathering and analysis of data applicable to electric utility service areas.
- Improvement of regional energy use data bases applicable to ORNL model.
- Gathering and analyzing data to improve specific aspects of the ORNL model (e.g., retirement functions, demand elasticities, equipment saturation, fuel splitting ratio's).

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ASSESSMENT OF ENERGY DEMAND MODELS*

D. Freedman, T. Rothenberg, and R. Sutch

INTRODUCTION

The main objective of this project is to describe and assess the midterm demand used in forecasting by the U.S. Energy Information Administration, to help users reach informed judgements about the probable accuracy of the forecasts. So far, the work has been largely qualitative. However, procedures are being developed to permit a quantitative assessment of some kinds of forecast uncertainty. These procedures may also facilitate the development of simpler and more robust forecasting models.

ACCOMPLISHMENTS DURING FY 1980

A major activity in FY 1980 was the assessment of the Regional Demand Forecasting Model[1] (RDFOR) and its data base, the Federal Energy Data System (FEDS).[2] This work can be summarized as follows:

An Overview of RDFOR

RDFOR forecasts what demand would be in a future year for each type of fuel, by consumption sector and geographical region, as a function of a vector of sector- and region-specific future prices. The demand surface has a constant matrix

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of own- and cross-price elasticities. Thus, the demand surface can be defined by specifying one point on it, together with a matrix of elasticities. The model has three components:

1. A system of log-linear demand equations whose parameters have been estimated using econometric regression techniques from historical data;

2. A procedure which employs the demand equations to derive the matrix of own- and cross-price elasticities defining the shape of the forecasted demand surface.

3. Another procedure which employs the demand equations to derive the matrix of own- and cross-price elasticities defining the shape of the forecasted demand surface.

The demand model (1) is the structural heart of RDFOR. It consists of a system of equations which set the log of quantity of fuel "demanded" (i.e., apparent consumption) equal to a linear function of the log of price and other variables. This model is dynamic in the sense that it involves lagged independent variables and imposes a time-dependent structure on the stochastic disturbance terms over the fitting period.

RDFOR recognizes ten DOE regions, four consumption sectors (residential, commercial, industrial, transportation), and 13 types of fuel (coal, natural gas, electricity, gasoline, distillate oil, residual oil, etc.). Estimates of the parameters are made for each sector and region. The total fuel demanded in each sector and region is predicted first, as a function of the average price of energy for that sector and region and certain other explanatory variables (such as population and income). The total is then shared out to individual fuels, with the share for each fuel depending on the price of that fuel relative to the average price of energy. Prices are taken as exogenous by RDFOR.

Data

RDFOR is fitted to the FEDS data base. This source contains most of the annual data required by the model for the period 1960-78. Reviews of FEDS[2] come to the following conclusions. Much of the data in FEDS is synthetic: the numbers are the result of imputation rather than measurement. Allocations to consumption sectors are often questionable, and the price series quite unreliable. The consumption sectors are sometimes inconsistently defined, especially with reference to agriculture, transportation, and government. The problem is most acute in the definitions of the so-called "extended" sectors. The deficiencies in FEDS could have serious consequences for RDFOR: namely, errors in the data could cause large errors in estimates of the coefficients, and hence in the forecasts. Furthermore, use of synthetic data seriously compromises the validity of the standard statistical procedures used to measure precision in estimates.[3]

Logical Structure

RDFOR is used to predict demand almost 20 years in the future. It extrapolates from a past of energy abundance into a future of energy scarcity. Under these circumstances, the choice of functional form is critical. The equations chosen by the architects of RDFOR cannot be derived from economic theory, or from detailed knowledge of the fine structure of the energy market. At best, these equations can be described as reasonable guesses, or convenient approximations. However, many different equations would be equally reasonable, and would fit the data equally well. Each set of equations would produce a different set of coefficient estimates, and hence a different set of forecasts.

When a model is used to extrapolate, its technical assumptions may have a major impact on the results. This point is illustrated in Figure 1, for the trend of (computer-generated) data against time. The straight line and the exponential curve both track the data quite well during the fitting period (1960-1980). But by the year 2,000, the exponential curve has gone off the graph.

The results obtained from RDFOR seem to be quite sensitive to the choice of indices,[4,5] the level of aggregation, and the functional forms assumed for the demand equations.[3,6] Simulation studies can be used to investigate the sensitivity of a model to its technical assumptions. In preliminary experiments with RDFOR-like equations, dropping the lagged income and weather variables tripled the estimated long-run own-price elasticity. These equations were fitted using Btu-totals for quantities, and Btu-weighted averages on prices. Moving to divisia indices (as used in RDFOR) tripled the elasticity again. Technical assumptions matter.

The choices made in RDFOR are somewhat arbitrary. On balance, it seems that rising energy prices will probably lead to more substitution of labor, capital, and technology for energy than the model suggests. In part, this view is based on the rigidities in the equations. And in part, it is based on the fact that not much substitution occurred during the fitting period. The arbitrariness in the choice of functional forms for RDFOR constitutes a major source of uncertainty in forecasts derived from this model.

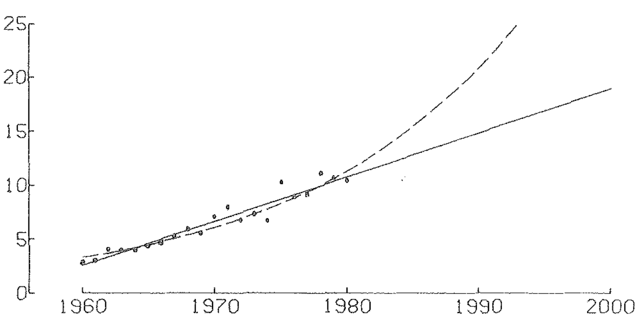

Fig. 1. In extrapolations, functional form matters.

Statistical Methods

The econometric and statistical methodology used in RDFOR is questionable. For example, the simultaneity of supply and demand is ignored; the constraints imposed on the coefficients are hard to justify; likewise, the assumptions on the stochastic disturbance terms seem arbitrary. These terms probably represent the effect of omitted variables and other specification errors. As such, strong correlations across fuels and across sectors may be expected. RDFOR ignores these correlations, and this may lead to serious errors in the estimates and in forecasts.

The strongest criticism of the methodology, however, is that RDFOR is over-fitted to the data. For example, the total industrial demand equation is fitted using generalized least squares, to account for interregional covariances. There are 10 regions and 17 years of data, from which are estimated 26 parameters, 10 variances, and 45 covariances.

RDFOR's many parameters allow it to track the historical data with artificial and misleading precision. As a result, small errors in the data, or small revisions to the data, are likely to have a disproportionate impact on the coefficient estimates. That is, the coefficient estimates are likely to be subject to large random errors. And unless the specification is exactly correct, which seems implausible, specification error can introduce large biases. This is illustrated in Figure 2. If the three points really follow the straight line, putting in an extra coefficient and fitting a parabola has very bad consequences. RDFOR seems to be doing exactly this sort of thing, in several hundred dimensions.

The statistical instability in RDFOR's structure was demonstrated in the simulation results described. The instability can also be seen by comparing the coefficients estimated in 1978 with the ones estimated in 1977. For example, in the total demand equation in the industrial sector, the long-run price elasticity estimated in 1978 was triple the one estimated in 1977, due to the addition of one data point and the revision of another.

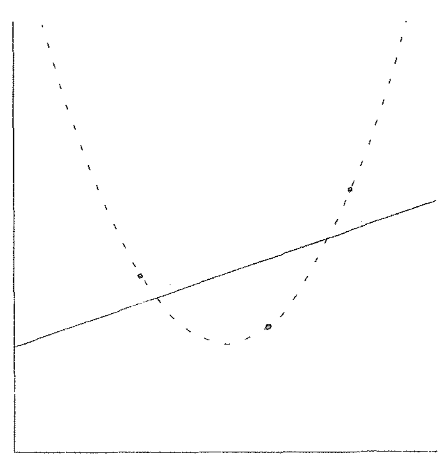

Fig 2. Over-fitting can cause serious bias.

PLANNED ACTIVITIES FOR FY 1981

In 1981, other demand models will be reviewed, including the Oak Ridge model of the residential sector.[7] Also, an effort will be made to develop some quantitative measures for the statistical uncertainty in the forecasts and the parameter estimates. The most promising technique is the "bootstrap," which is explained in detail elsewhere.[8,9,10] This technique involves stochastic simulation, to test the model against its own assumptions.

In brief, the model has been fitted to data by some statistical procedure, and there are residuals, or discrepancies between actual and fitted values. Some stochastic structure was imposed on these residuals, explicitly or implicitly, in the fitting. The key idea is to resample the residuals, preserving this stochastic structure.

Assuming the model and the estimated parameters to be right, the resampling generates "pseudo-data," both for the past and for the future. Now the model can be refitted to the pseudo-data for the past and used to "forecast" the pseudo-data for the future. In this artificial world, the error of forecast, and the errors in the parameter estimates, are directly observable. The Monte Carlo distribution of such errors can be used to approximate the distribution of the unobservable errors in the real parameter estimates and in the real forecasts. This gives a measure of the statistical uncertainty in the parameter estimates and the forecasts.

A variation on this idea can be used to compare two models, testing each one against the assumptions of the other. This involves generating the pseudo-data with one model; the second model is refitted to the pseudo-past, and used to predict the pseudo-future. Then the roles of the two models are interchanged. In this way, the bootstrap can be used to select forecasting equations which are relatively insensitive to specification error.

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ENERGY DEMAND AND CONSERVATION IN KENYA: INITIAL APPRAISAL

ENERGY DEMAND AND CONSERVATION IN KENYA: INITIAL APPRAISAL*

L. Schipper† and J. Hollander†

INTRODUCTION

One of the most important factors in the growth in world oil consumption since 1972 has been the economic growth of the developing world. While a few nations account for most of the increase in oil use, all developing countries (LDCs) find that oil is an important ingredient in today's economic growth. Unfortunately, little is known of the nature of the demand for oil and other fuels traded commercially on world markets.

In this research, we take a detailed approach to accounting for energy end uses. We disaggregate important energy end uses according to various economic variables or physical activity levels (miles driven, tons produced, households) and into energy intensities (joules/mile, joules/ton, kWh/household).

To do this is to pay particular attention to the economic and demographic structure of the country: How many autos are there, and how far are they driven? How much steel is produced by individual plants and at what energy intensity? How many people visit a particular hotel in a particular year? In this way we can relate energy demands to specific economic activities that are often directly related to the degree of economic development in Kenya, particularly in the cities. This methodology arose in consideration of energy use in developed countries, such as in the study of the U.S. and Sweden published by Lawrence Berkeley Laboratory in 1976.[1] As in that study, the goal of the present work is to first account for energy flows, then to find examples of energy conservation in practice, and finally to make appropriate recommendations for further analysis and implementation of conservation in the modern sector of Kenya's economy.

Conservation in Developing Countries

Why should developing countries worry about energy efficiency and conservation? It is often contended that their per capita use among the people and institutions actually coupled to the market economy is so little that there is literally nothing to conserve. We found the opposite to be the case. Many factory managers and buildings experts were concerned about the cost of energy; government officials and oil company planners were worried about the cost to Kenya of importing increasing amounts of increasingly expensive oil. Ironically, the East African Oil Refinery (EAOR) was a profitable earner of export dollars before the oil embargo, since a large portion of the crude refined there was reexported, the profits paying for the net outflow of hard currency to buy all the crude. The oil embargo and subsequent price rise changed that situation.

The other important concern expressed in Kenya is over the commercial/noncommercial interface among energy supplies. Most world statistics only count commercially-sold energy, particularly that energy used in activities that are accounted for in the nominal GNP. Of course, there is intense competition among commercial and noncommercial

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energy sources--deforestation and high-cost charcoal may make commercial gas cylinders or solar cooking the only viable options for rural families who cook; low-cost commercially sold wood replaced oil (until recently) in one of the manufacturing firms we visited; bark could serve as a firing fuel for a paper mill we visited except that it proved to be cheaper in the past to debark trees where they were cut, by hand, and leave the residue behind. Oil is used instead to raise steam at the mill.

Much interaction and potential substitution exists among commercial and noncommercial or renewable energy sources. The problem is just that the average Kenyan, whether rural or urban, has little income with which to buy equipment that would make electric or gas cooking possible; has little choice in how efficient higher-cost wood is turned into charcoal; and must interact with a market economy that is more or less dependent on the inflow of commercial imported oil for its health. Better understanding of the efficiency of end-use energy in Kenya, and recognition of the many ways in which commercial and noncommercial energy sources, efficiently deployed, could complement each other, may be the key to Kenya's energy future. For as oil prices rise, internationally, Kenya, like the countries of the OECD, may find that as all other energy sources are also rising in cost, the most effective weapon against these costs remains energy conservation, the effective use of all forms of energy.

End Use Analysis

Industrial Energy Use

There exists no detailed surveys, by firm or product, of industrial energy use in Kenya. However, we found very quickly that the requisite data exist, given the relatively small number of firms listed in the Directory of Industries (1974 and 1977 editions). We did not have time to survey electricity and fuel use of each type of producer, but were able to sample data from individual firms, oil companies, and the East African Power and Light Company (EAPL). Finally, we conducted on-site interviews with engineers responsible for heat and power in more than a dozen important firms. Eventually we plan to completely classify energy use in Kenyan industries and measure energy intensities, and thereby the potential for increased energy efficiency in industry.

Table 1 gives an overview of energy intensities in key firms. For several years, data or

Table 1. Industrial energy intensities.

Type	Electricity (kWh)	Fuel (10^3 Btu)	Output Unit	Year	Notes (Oil Types)
Lorries	*	1850	Lorry	1978	--
	610	1690		1979	--
Tires	1.1	15.0	Pound	1975	Residual
	0.74	9.65		1978	--
	0.71	8.40		1979	--
Oil refining	11.5	1480	MTon	1973	Crude losses
	16	1480	MTon	1977	--
Cement					
1.	77.0	5000	MTon	1975	Residual
	81.2	5300	MTon	1977	--
	73.8	5200	MTon	1979	--
				1976	--
2.	105	3100	MTon	1977	--
				1979	--
				1976	--
3.	95	3600	MTon	1977	--
				1979	--
Paper	-	4500	MTon	1977/78	Purchase electricity only
	105	4170		1978/79	
	196	3675		1979/80	
Hotel					
1.	16.1	130	Guest-day	1975	Distillate
	14.3	97	--	1979	(compared with 1975)
2.	35.5	290	--	1977	--
	23.7	240	--	1979	--

* Auto assembly electricity data omitted where meter was not functioning.

comparative figures from other parts of the world are given. The EAOR increased its size after 1973 but did not increase output. Consequently efficiency fell. A conservation program regained some of these losses. As output increases, the energy intensity will fall again. Given the rapid pace of growth of industry in Kenya, we expect to see new technologies in other industries that will allow output to increase considerably faster than energy use, particularly as energy prices rise.

Commercial Buildings

Commercial buildings include many kinds of enterprises; the most important for Kenya are public services (schools, hospitals), hotels and restaurants, office buildings (including governmental buildings), and stores. Some of these enterprises are described in Table 2. In the case of one major hotel, we found that overall electric power use per guest per year had decreased substantially from 1976 to 1979, in part due to the recent initiation of a conservation campaign. The drop in electricity use is dramatic, as indicated in the bottom of Table 1.

Homes

Commercial energy use in the residential sector is characterized by extreme concentration into a small fraction of all households. Complementing this situation is the relatively minor but growing use of kerosene for lighting and cooking and for somewhat greater use of cylinders. For cooking, the majority of Kenyans use charcoal as fuel for domestic purposes. This use may be as great as five times the sum of all commercial energy use. (Table 3)

We have been able to analyze electricity use further, using data from EAPL. The largest residential consumers register their electricity consumption for water heating on a special tariff (with an electronic signal interrupter). In 1976 there were 27,000 hot water customers, 51,000 regular residential customers (including the hot water), and 56,000 customers using very little electricity, most living in rural areas or in low-income estates. The designated income group for each housing tract, however, does not always reflect the incomes of the people who actually live there, due to subleasing. Similarly, data of wealthy households include use of energy in servants' quarters.

What is missing from this electricity use picture is the complementary use of fuels. While electric cooking probably dominates in those homes in the first row of the table, it is clearly absent in the case of small users, or for those for whom charcoal, kerosene, or in some cases gas is more important. One house we visited had switched from gas to charcoal, because the gas stove had exploded. We obtained an estimate of country-wide kerosene and liquid petroleum gas (LPG) consumption from Kenya Shell. This estimate includes sales of small lots of packaged kerosene and bulk kerosene sold for resale, as well as lots of small gas cylinders. We may have overestimated consumption of these two fuels in the residential sector since

Table 2. Provisional breakdown other electricity uses.

	Customers	Price/kWh (Kenyan cents)	Total Sector (10^6 kWh)	Remarks
Commercial				
Small[a]	20,000	55	132	1976
Large[b]	400	55	140	1976
Large industry	490	27.3	356	1976
Agriculture Nairobi	50			
(large estates)		40	13	--
Elsewhere	50			--
Nairobi Only				
Hotels	24	35	19.6	1977
	25	45	14.4	1978
(Coastal Region)	40	--	23.9	1978
Hospitals			15.7	1977
Offices, Banks (excluding government)	22	50	11.4	1977
	22	60	12.6	1978
(New customers only)	3	60	1.9	1978
Kenyatta Center	--	--	2.7	1977

[a] Mostly shops.
[b] Mostly large buildings, schools, some light manufacturing.
[c] Agriculture includes farms and estates.

Table 3. Residential energy, 1978.

Type	Customers	Price KC*	Use/Year (kWh)	Year
			Per Customer	
Regular electricity	51,000	33	3,000	--
Small users (electricity)	56,000	125	250	--
Hot water (electricity)	22,000	18	4,815	--
			Total Country	
Gas cylinders	--	--	90 GWh	1977
			103 GWH	1978
Cooking and lighting	--	--	405 GWh	1977
Oil	--	--	645 GWh	1978

*KC = Kenyan cents.

small stores or restaurants may use small quantities of these fuels as well.

The prospects for solar water-heating in Kenya are bright. We examined the records of one of the major assemblers and suppliers of solar water heaters. Based on an estimate that he has installed 2000 m^2 of collector thus far (with each m^2 providing about 9000 Btu/day of hot water), we find that installed residential and commercial hot-water systems save Kenya about 1.5×10^6 kWh/yr that would have been required in the form of electricity (more if required as gas or oil, for heating this water). Moreover, a great deal of this electricity would be under normal commercial tariff, in that the electricity is used in schools or hospitals. The total investment cost for these collectors has been approximately 3×10^6 Kenyan Schillings (KS). If normal tariff electricity cost 50 Kenyan cents (KC)/kWh in 1979, then the yearly savings to Kenya from this investment is approximately 750,000 KS.* The manufacturer we interviewed pointed out that business was booming, and provided us with the examples of new projects (a school, a hospital, and a condominium) that he expected to complete soon.

Conservation in Kenya

We noted at several sites that energy conservation programs were in progress. In every case, the person responsible cited higher prices for fuels and electricity as the primary motivation. As to our pessimism over the lack of interest on the part of some firms, it is well known from economic observations that the response to a price increase, be it steady or on-time, takes between a few and tens of years, to take effect. The reason is simply that the greatest changes in energy use take place with the least cost when new equipment is built. Thus the evidence we have seen so far indicates conservation is beginning to take place in Kenya. But we found many opportunities worth investigation. We noticed several buildings that could be retrofitted to reduce solar gain and hence air conditioning needs. We also note that homeowners can implement the following conservation measures: (1) add insulation to hot water heaters (in the U.S. some utilities now provide this as a service), (2) shade windows, (3) keep refrigerator coils clean, and (4) make a conscious effort to reduce the number of miles driven.

Since the beginning of 1979, energy prices have begun to rise in real terms in Kenya. Our visit in the summer of 1980 came after a severe drought had limited electricity use. We found interest in conservation more abundant than ever before, and some of the efforts of 1979 are reflected in the data in Table 1. In FY 1981 we will complete as many details as possible in the end-use balance for Kenya to identify more trends in conservation, and we will interview personnel at up to fifty factories and a dozen hotel organizations to chart the progress in conservation, as well as to investigate past and future possibilities for solar hot water heating in Kenya.

Foreign Trade and Embodied Energy

An extremely important source of energy often omitted from national data is the energy incorporated in imports and exports. A brief calculation

* This calculation assumes no standby losses for either system. We count only the hot water actually made available by solar systems. If all this were produced from the low cost interruptible tariff, the savings would be considerably less, on the order of 300,000/year. Either way, the rate of return is greater than 10%.

based on the known balance of nonenergy trade between Kenya and the rest of the world suggests that Kenya imports more energy embodied in goods and services that is exported. This is not at all surprising, but should be noted in any study looking at end uses of energy.

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INTERNATIONAL RESIDENTIAL ENERGY CONSERVATION*

L. Schipper and A. Ketoff

INTRODUCTION

International comparisons of residential energy use have been hindered in the past by lack of data and common measuring systems. In this paper we report on ongoing efforts to disaggregate data on residential space comfort and appliance energy use for major member countries of the Organization For Economic Cooperation and Development (OECD). Indicators of residential energy consumption sector structure (i.e., dwelling size, number of appliances, incomes) and of intensity of energy use (i.e., energy use per degree day, etc.) are developed and compared for various countries. Comparisons among countries suggest that, in certain countries, much scope exists for energy conservation by reductions in energy intensity. At the same time, rising incomes in many countries allow greater use of heating, hot water, and appliances. Success in predicting future demand depends on our ability to separate the factors that have contributed to energy demand growth in the past, including greater efficiency, from those that will determine energy demand growth in the future.

Since FY 1979, LBL has been investigating residential energy use in major industrialized countries† in an effort to increase the Department of Energy's knowledge of the factors that shape worldwide demand for oil and other forms of energy. Since there has never been an international data base covering residential energy use, the LBL team began by collecting primary data on economic and demographic features of the major countries in the study.[1] At the same time, we examined the factors that seemed important a priori in shaping residential energy demand--factors that were usually overlooked in the cursory analyses of residential energy use or fuel consumption that have appeared in various placed during the past few years.[2] Our disaggregated approach follows the structure-intensity format used in Schipper and Lichtenberg:[3]

Energy use = Activity level x Energy/unit activity.

Data sources on structure are well known, though often unfamiliar to energy researchers. We found it necessary to study and extract much data from housing ministeries, censuses, utility surveys, and house-building companies. The latter are important because we try to capture not only the state of the building stock in a given year, but also the characteristics of each year's new stock.

Data sources for energy end use estimates have been varied. We encountered ten careful studies of historical demand by function in Germany, several from Japan (and the U.S.), but only one each from Italy, France, and Canada and virtually nothing of a historical nature from Sweden, where information is scattered through a score of unrelated studies. Not surprisingly, then, we turned to unofficial data sources, oil and gas companies, electric utilities, trade associations, housing and census bureaus, academic research groups, even professional societies. While we found studies that have attempted to reconstruct energy end use for at least one key year, we have not found systematic attempts in each country to analyze and understand the overall historical picture.

Our goal is to follow the evolution of space-heating, water-heating, cooking, and appliance energy use by fuel over the 1960-1980 period. Data have permitted partial success; for some countries primary data or analysis of the entire period were forthcoming, while for others little or no information was available. Our analysis of Italy[2,4,5] relied on our own reconstruction of many items of information, while our present effort towards completing the end-use data base[6] includes an effort to rebuild Swedish end-use data from original material[7]. Information from other countries came from sources too numerous to mention, but we have relied on primary data from energy companies, studies commissioned by governments or private institutions, and technical studies of aspects of energy consumption that can be generalized. Not surprisingly, we found little use for so-called official government data; such figures are usually too highly aggregated or poorly defined.

Residential Gas Use

At an early stage in our FY 1980 work we presented a detailed study of the use of gas in

* This work was supported by the Office of Applied Analysis, Energy Information Administration of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

† Canada, England, France, Germany, Italy, Japan and Sweden.

households in several countries.[3] We focused on the physical factors that influence quantities of gas used, such as economic and lifestyle indicators, ownership of equipment, energy intensity of equipment use, gas prices, and conservation potentials. Detailed comparisons of gas use among countries and over time are possible.

We discuss the major uses for gas--cooking, and heating water, and since 1970, space-heating--and how they have evolved during the past two decades. We show the ownership of gas-using devices--the structural component of energy demand--and then examine the intensity of gas use on a per unit output basis. Changes in intensity are important signs of energy conservation. We summarize our findings in Table 1. Included herein are data on households and housing stock that comprised the bulk of our FY 1979 and early FY 1980 work.

While there are good indications that the intensity of gas use is falling, we have little systematic information on what people in each country may be doing to reduce heating gas use.

- For the U.S., the American Gas Association estimates that per household and degree day measures of heating-gas only, decreased 12% during the 1973-1978 period on average compared with 1967-1972, and by 16% in 1977. (The heating season begins in the fall of the year cited.)

- For Canada, Canadian Gas Association estimates an 8% drop in consumption in 1979 compared with 1972, corrected for weather but including all uses. Canada Shell finds a 10% drop in the weather-corrected heating gas consumption for single-family dwellings (SFD) only.

- For France, data from the Agence Pour Les Economies d'Energie show a slight increase from 1973-1977, though there was a clear decrease during the intervening years. Here the effect of rapidly growing central heating probably obscures the true conservation effect.

- For Germany, estimates were unavailable, but an enormous increase in gas central heating, from 1.2 million to 3.6 million dwellings from 1972-1979 was observed. While the centrally heated share of gas-heated dwellings increased from 56% (1972) to 74% (1977), the increase in heating-gas corrected for climate was much smaller, indicating that conservation offset much of the expected increase in gas use per dwelling due to central heat.

- Lifestyle differences that lead to differences in gas requirements for cooking and hot water should be studied. In particular, how much more or less gas per home might be demanded for these uses because of lifestyle changes?

- Technological differences in gas appliances for all uses should be compared from nation to nation. Are there hidden barriers to one country's adoption of another country's device, such as rules regarding venting, capacity or flues?

- Methods developed by LBL should be systematically applied to each country's conservation possibilities, both to compare technologies and costs and to see how large potentials in each country really are.

- Differences in energy-use patterns that have arisen since 1972 in each country should be examined closely, both at the macro level (as in the present work) and systematically at the micro level through metering, surveying, and interviewing. We will do this work in the near future.

The study of gas use established the feasibility of reconstructing historical facts of residential energy use using data still existent in archives of energy companies and government bureaus. This knowledge proved useful in our continuing effort to examine all residential fuels and uses.

Overall Residential End Uses

Working from an increasing supply of primary data from the countries under study, we completed our accounting of all fuel and electricity use and began analyzing end use by fuel types. Data on oil and electricity use were on a par with that which we had found on gas, while data on solid fuels were poor. By the end of FY 1980, the data base was substantially complete, and we began to prepare for the Energy Information Administration the completed tables of energy use by fuel of each country's energy use, and a comparison of indicators of energy use across time and countries.

For Italy and Sweden, we were forced to assemble country data from small bits of information scattered through the literature; there is little integrated historical analysis of end use for the period in question. In "reconstructing" residential energy use, we use estimates of unit consumption for appliances and other uses to allocate all energy forms over all end uses. Thus our balances for Sweden separately show cooking, hot water, and electric-only appliances, whereas so-called "official" data give "heat/hot water," sometimes disaggregated by fuel, and "appliance electricity." Gas, which played an important role in cities in the 1960's is all but ignored. Such reconstructions, we feel, show many important facets of energy consumption dynamics that are important to understanding the changes in energy use patterns over the past few years, particularly when the government has made large sums available to consumers for energy conservation projects. Lacking any official breakdowns, we were forced to make our own estimates for Sweden and Italy.

By contrast, integration of rich data from Germany was aided by the appearance of a report

Table 1. Residential gas end use breakdown: preliminary results.

Year	United Kingdom 1961	1972	1977	Canada 1960	1972	1977	Germany 1960	1972	1977	France 1962	1973	1977	Italy 1960	1972	1975	Japan 1965	1972	1977
Heating																		
Occupied dwellings (10^6)	15.9	18.9	20.3	4.6	6.5	7.2	16.2	22.0	24.2	14.6	16.9	18.3	12.8	15.5	16.1	20.9	29.4	32.0
Central heat (%)	8	37	51	67	81	84	14	48	57	20	44	58	-	41	43	4	-	12
Gas heat (%)	15[a]	34	55	16	34	37	1.6	12	17	8	15	21	5	18	23	14[f]	25[f]	38[f]
Natural gas and city gas (%)	-	-	51	15	33	36	1.3	9.5	16	8	15	21	5	17	22	-	-	-
LPG (%)	-	-	4	1	1	1	0.3	-	1	-	-	-	0	1	1	-	-	-
Gas central heat (%)	-	14	26	13	31	35	0.3	6	12	1	10	14	-	10	13	-	-	-
Gas/dwelling (GJ)	-	50	-	132	133	122	20	67	67	47	51	52	20	23	24	5	4	3
Gas/dwelling/degree day (MJ)[j]	-	21	-	29	27	27	6	18	20	19	23	26	9	9	11	4[g]	4[g]	4[g]
Total gas (PJ)	-	321	-	97	293	328	5	141	260	55	130	201	8	70	92	15	33	40
Hot Water																		
Gas share (%)	15[b]	26	38	18	30	34	11	18	-	17	23	30	-	12	13	-	125[h]	-
Gas/dwelling (GJ)[k]	-	7	-	37[d]	36[d]	37[d]	10	7	9	12	11	9	-	14	16	-	6[i]	-
Cooking																		
Gas share (%)	66	58	54[c]	20	13	9	40	29	25	43	42	40	80	90	94	0	98	-
Gas/dwelling (GJ)	-	7	-	d	d	d	2	2	-	8	6	5	4	5	5	-	4	-
Total Energy (all dwellings)																		
Total (PJ)	1484	1519	1586	734	1190	1297	1000	1845	1970	686	1523	1540	386	920	1018	526	931	1076
Gas (PJ)	140	479	701	142	369	405	54	185	321	72	273	353	-	167	250	136	347	439
Natural gas (PJ)	0	242	690				0	117	281									
Natural gas and city gas (PJ)				136	355	393				38	205	289	-	130	209	96	207	257
City gas (PJ)	137	234	5				48	68	30									
LPG (PJ)	3	3	6	6	14	12	6	20[e]	27[e]	34	68	64	-	37	41	40	140	182
Electricity (PJ)	138	313	309	80	199	289	46	200	271	23	108	175	34	90	106	78	218	287

MJ, GJ, and PJ refer to megajoules (10^6J), gigajoules (10^9J), and petajoule (10^{15}J) respectively.

[a] 1964 figure.

[b] 1966 figure.

[c] Gas also used for refrigeration in 3% of households.

[d] Cooking and water.

[e] LPG excluded from heating. Hot water also uncertain.

[f] Refers to gas stove saturation, including gas heat as secondary system.

[g] Degree Day base 14°C.

[h] Total saturation hot water plus bath water heaters.

[i] Average consumption of both appliances in h.

covering the period of interest by P. Sueding of the University of Koein. For Canada, the major part of the work was done by Canada Shell, to which we added refinements to make Canadian data compatible with that of other countries. Data for recent years from France and Japan was available from various sources, but data for earlier years from these countries and for the UK, where only one year had been carefully analyzed, were incomplete. While our data gathering is complete, we will attempt to make any worthwhile additions or corrections to our data base in FY 1981.

Following the scheme outlined above, we present in Table 2 summary data on residential energy use for all fuels for the countries we have studied. Note that not all countries' data sets are complete at this time; nevertheless the results we cite, based both on our surveying of existing studies and our derivations from other data show the pattern of residential energy use is changing in different countries. We use several summary indicators in this aggregated table:

- Space-heating per household, and per square meter (where possible) normalized to degree days;
- Water-heating and cooking, the two uses with the greatest substitution among fuels and electricity, per dwelling. The reader can derive the per capita values.
- Electric-specific appliances, that is, those that use primarily electricity for motors and very little for heat energy, on a per capita, per houselhold, and per unit of real disposable income basis.

Aside from space-heating, we warn readers against comparisons of energy uses across national boundaries until more is known about equipment, equipment use (e.g., quantities of hot water consumed) and other aspects of lifestyle that bear on energy use. Similarly, little is known about differences in consumer habits, preferences, or lifestyles that may influence consumer responses to changes in incomes and energy prices, the two parameters recognized as the most important determinants of energy use. Finally, many countries have developed differing approaches to conservation, both through research, and through programs of loans, grants, restrictions, or standards. Little quantitative information on the effects of these programs has been developed. Investigating these differences in detail as well as the approaches to conservation and their success, will comprise the bulk of our work in FY 1981.

Preliminary Findings

What does our historical analysis of residential energy use tell us? It is well known that space-heating dominates energy use in most countries. It appears, to the surprise of many, that structural changes, related to increases in income, as manifested in 20-40% increases in living space per capita, large increases in the penetration of modern heating systems, and even increase in the indoor temperatures in centrally-heated homes (in Sweden and Germany) account for much of the increase in space-heating use in most countries in Europe. There is evidence that building shells have become progressively tighter since 1945 in Sweden, and other countries have introduced building codes that should result in great decreases in the intensity of heating in the future. At the same time, the increase in central heating obscures gains made in the efficiency of heating, unless energy uses are carefully disaggregated.

Central heating penetration continues to increase. In 1980, only Sweden, Canada (and the U.S.) exhibit virtual saturation of central heating by any form. Germany is intermediate, France, Italy, and Great Britain are still growing markedly, while Japan remains without central heat. This means that there is still potential growth in heating demand in major countries. Table 2 gives indicators of both space-heating structure and intensity. In future work, we will present estimates of space heating disaggregated further by fuel and dwelling type.

Other Energy Uses

What about measures of activity levels besides those of space-heating? Structural data on appliances are very important for understanding the tremendous increase in electricity use seen during the 1960-1975 period. The dominant cause for this growth is the acquisition of appliances, much more so that the increased energy use or size of individual appliances. For example, data from France, Italy, Sweden, and Germany show little change in annual energy use for electric stoves and, in most cases, for refrigerators. On the other hand, many refrigerators in Europe do not contain large freezing compartments that freeze to -15°C. This feature, common in the U.S. or Canada, increases energy requirements for refrigeration.

In Table 3, we list the saturation of major appliances for most countries in our study. Growth rates for ownership of the major appliances fell typically in the 10-20%/yr. range through the early 1970s. Available information does not tell us all we would like to know about the characteristics of each appliance. Still, it is easy to see that the growth in stocks drives the growth in electricity consumption. And there appears no trend towards American-size refrigerators; American/Canadian levels of hot water consumption; or American-sized washers, dryers, dryers, TV, etc.

Here a difficulty for analysis of behavior and energy use is evident. In fact, it is very important to understand the characteristics and use patterns of major appliances. We suspect that the estimates of annual energy use do not carefully count both technical efficiency and usage patterns. That is, we really do not yet know the quantities and temperatures of hot water consumed by people in various countries. Yet a prescription for motivating consumers to save energy by changing hot-water use requires an understanding of how hot water is used, and where the big--and small--savings through behavior change may be. While today most countries' residential energy use is dominated by heating, the nonheating component in the U.S., Canada, and Sweden is large, and it is growing in other countries relative to heating. Therefore,

Table 2. Residential energy use breakdown: preliminary results.

Year	United Kingdom 1961	United Kingdom 1977	Canada 1960	Canada 1976	Germany 1960	Germany 1977	Sweden 1960[c]	Sweden 1977	France 1962	France 1977	Italy 1960	Italy 1975	Japan 1965	Japan 1977
Heating														
Occupied dwellings (10^6)	15.9	20.3	4.4	7.0	16.2	24.2	2.58	3.58	14.6	18.3	12.8	16.1	20.9	32.0
Persons/dwelling	3.0	2.8	3.9	3.1	3.5	2.6[q]	2.8	2.4[q]	3.2	2.9	3.9	3.5	4.5	3.4
Dwelling area (m^2)	-	80[q]	-	-	67.6	75.1[q]	73.2	81.8[q]	65	72	58	69	72.5	77.1
Single-family dwellings (%)	-	49	65	56[q]	48	45[q]	47	45	62	58	23	29	71	65
Central heat (%)	8	51	67	84	14	57	75	97	20	58	-	43	4	12
Fuel heat (%)	-	-	99	87	99(1)	89(4)	100	65(22)	20[d]	55[d]	71	90	67[h]	97[h]
Fuel/dwelling (GJ)	-	-	140	132	54	70	58	83	73[d]	89[d]	22	70	14	9
Fuel/dwelling/degree-day (MJ)	-	-	30	28	17	21	14	20	24[d]	33[d]	10	33	10[i]	8[i]
Electric heat (%)	0/65	11/72	0.5	13	0	7/33	0	13	0/-	3/4	-	6	16[j]	40[j]
Electricity/dwelling (GJ)	-/3	17/2	79	87	-	33/2	-	75	-	31/45	-	14	2	2
Electricity/dwelling/ degree-day	-/1	8/1	17	18	-	-	-	14	-	12/17	-	7	1[i]	2[i]
Total fuel (PJ)	-	927[q]	413	776	800	1485	226	300	514[e]	1177[e]	201	1019	197	305
Total electricity (PJ)	33	68	2	79	0	70	0	32	1[e]	33[e]	4	14	6	22
Hot Water														
Fuel share (%)	-	66[q]	34	46	28	61	75	87[o]	-	74	-	34	k	k
Fuel/dwelling (GJ)	-	18[q]	-	30	-	9[b]	-	22	-	12	-	16	k	k
Electric share (%)	35	66	47	51	19	39	-	13	11	28	9	42	k	k
Electricity/dwelling (GJ)	7	6	-	23	7	6	-	14	-	7	3	4	k	k
Total hot water/capita (GJ)	-	5.7	6.0	7.7	1.7	2.9	-	8.4	1.4	3.9	0.9	2.0	1.6	3.3
Cooking														
Fuel share (%)	74	63[p]	42[o]	12	89	29	32	2	95	90	94	99	k	k
Fuel/dwelling (GJ)	-	7[p]	-	7[a]	3.8	5.0	-	-	2.4	4.7	3.4	5	k	k
Electric share (%)	35	41[p]	58[o]	88	11	71	68	~98	5	10	6	1	k,l	k,l
Electricity/dwelling (GJ)	5	4[p]	-	3.6	2.5	1.7	2.2	3.1	3	3	3	3	k,l	k,l
Total cooking/capita (GJ)	-	2.1[q]	1.1	1.2	0.9	1.2	-	1.0	0.7	1.4	0.9	1.4	1.7	2.9
Appliances														
Use/dwelling (kWh)	750	1810	1100	4100	215	1535	970	3130	534	1418	220	670	940[m]	1853[m]
Use/dwelling (GJ)	3	7	4	15	1	6	4	11	2	5	1	2	3[m]	3[m]
Use/dollar disposable income (KWh)	0.3	0.2	0.2	0.5	0.02	0.1	0.2	0.4	0.09	0.14	0.1	0.2	0.2[n]	0.1[n]
Total Energy														
Total (PJ)	1484	1586	734	1297	1000	1970	-	379	686	1540	386[g]	1018	526	1076
Gas (PJ)	140	701	142	405	53	321	-	-	72	353	-	250	136	439
Natural gas (PJ)	0	690	┐	┐	0	281	-	-			-			
Natural gas and city gas (PJ)			136	393					38	289		209	207	257
City gas (PJ)	137	5	┘	┘	48	30	-	4						
LPG (PJ)	3	6	6	12	6	27	-	-	34	64	-	41	140	182
Oil (PJ)	73	147	416	571	111	1106	173	235	158	836	-	622	60	325
Coal (PJ)	┐	344	┐	┐	┐	28	20	0	┐	147	-	┐	66	20
	1132		14	780	172				433			40		
Wood (PJM)	┘	65	┘	┘	┘	26	10	-	┘	25	-	┘	42	5
Electricity (PJ)	138	309	80	289	46	271	26	78	23	175	34	106	78	287
District heat (PJ)	-	-	-	-	10	64	-	52	-	4	0	0	0	0
Electricity (TWH)	38	87	22	80	13	75	6	22	6	49	9.4	29	22	80

Notes to Table 2

"Occupant Dwelling" refers to households except when the number of households is greater than the number of dwellings, as is the case for Germany and Japan in the first year given. "Persons per dwelling" refers to only conventional dwellings from single detached dwellings (including farms) to multiple dwellings, but excludes persons in institutions, military barracks, etc. "Single-family dwelling" definitions vary among countries, but in Sweden, Germany, Italy, and France they include one-and two-family dwellings and row houses. In the United Kingdom, the totals are enlarged by great numbers of the latter. In Canada, row houses are excluded here. In Japan, the definitions do not generally correspond to those in Europe.

In "Heating," fuel heat includes all fuels except district heating. Only for Germany and Sweden, the figures for the district-heated share are given in parenthesis. For France, the figures refer only to central heating. "Electrical heat" refers only to central heating for Canada and Sweden. For the United Kingdom and Germany, the two figures presented show first central, then portable electric heating. For France, the second figure refers to all systems while the first is only central. For Italy and Japan, where central electric heat is insignificant, the figures refer to all systems.

In "Hot water," saturation may add to less than 100% as some homes have none, or more than 100%, because of multiple equipment. In the case of United Kingdom and Japan the totals refer to numbers of appliances per home. In each country a small percentage of homes have no hot water except for kettles.

"Appliances" excludes cooking where possible. We have extracted electric cooking from data from Canada (1000 kWh/yr), Sweden (about 600 kWh/dwelling in 1960, 800 kWh/dwelling in 1977) where sources gave only a total figure. We have also attempted to extract electric water-heating from Swedish data. As small electric heaters are often missed, there is a chance that some of this heating has been counted both under heating and also under appliances.

Fuel totals come from the International Institute of Environment and Development and from the Department of Energy, (United Kingdom); Statistics of Canada and Canada Shell (Canada); Deutsche Esso, BP, and various German reports (Germany); Agence pour les Economies d'Energie and CEREN (France); ENI, WAES-Montedison, and ENEL (Italy); Institute for Energy Economics (Japan). We have separated liquid petroleum gas (LPG) from oil totals in some countries and shown it under gas. Where solids or gases are only given in the aggregate, we give the aggregate figure on the intermediate line.

We give only district heat in those countries and years where it amounts to at least a few percent of total consumption. Dwellings in France, Sweden, and Germany had district heating. The Swedish/German figures for the number of dwellings are given in parenthesis in the breakdown of fuel-heated dwellings. Energy consumption is given in totals. In Germany, 10-12% of the district heating fuel total can be attributed to hot water; in Sweden the amount is about 18%.

MJ, GJ, and PJ refer to megajoules (10^6J), gigajoules (10^9J), and petajoules (10^{15}J), respectively.

[a]Gas cooking and water together. Our breakdown is shown, based on an Ontario estimate of gas used to heat water.

[b]Hot water uncertain.

[c]Demographic data 1960; energy 1963.

[d]Only central heating.

[e]Includes second homes.

[g]These data appear unobtainable. Estimate of total from WAES.

[h]Refers to homes with at least one fuel stove, plus part of the homes that have a gas stove (the other share of gas stoves being owned by homes already considered fuel heated, thus having at least one fuel stove).

[i]HDD base = 14 degree C.

[j]Only stoves, no kotatsu (small heaters for feet) considered.

[k]These data are available only for 1973. For that year, it is possible to know the amount of each fuel for each end use, but not the share.

[l]Electricity is almost not used for cooking tables, only for rice-cookers and microwave ovens.

[m]Includes some electric appliances for cooking (microwave rice cooker).

[n]"Disposable Income" not available, so we use "Private Income."

[o]1961 data.

[p]1972 data.

[q]1975 data.

Table 3. Saturation and yearly consumption: electric appliances in 1977.

	Cooking		Water Heater		Dish Washer		Clothes Washer		Refrigerator and Freezer	
	(%)	(kWh)	(%)	(kWh)	(%)	(kWh)	(%)	(kWh)	(%)	(kWh)
Canada	86	-	50	-	22	-	76	-	99/54	-
West Germany	71.3	600	39.0	1500	15.0	880	88.0	450	140	400/750
France	8.0	875	27.0	1700	12.0	900	72.3	300	91.6	410
Italy	1.2	910	41.0	1080	9.7	1200	75.0	550	97	222
Sweden	95.0	830	15.0[a]	2500[a]	17.0	370	50.0[b]	400[b]	160	660
United Kingdom	44.7	1970	66.1	1575	3.0	465	75.7	195	115	445

Source: Union des Producteurs et Distributeurs D'Electricite (UNIPEDE). German data from Verein der Deutschen Elektrizitaet Werken. Canadian data from Annual Household Surveys. Other Swedish data from Foerening foer Rationella Electricitet Anvaending.

[a]Swedish hot water estimated from central systems in centrally heated all-electric homes.

[b]Building-size appliances are not considered.

the consequences of a careful attempt to reduce nonheating energy use could be much greater in the future. As we suggest, however, that effort will depend greatly on intimate knowledge of how appliances are used.

Our preliminary assessment of available data suggests that the growth in nonheating energy use in residences has been propelled largely by structural growth, i.e., that of incomes. This finding, coupled with knowledge of the saturation of appliances, the characteristics of new models, and the fact that most new kinds of home appliances tend to be nonenergy intensive (i.e., involve little or no use of heat) suggests that future structural changes, i.e., the onset of ownership saturation, will retard the growth in the residential demand for energy, particularly electricity, in the future, relative to rising incomes. The slowdown in the growth of electric appliance energy use relative to income, which we observed in every country, is suggestive that this is taking place already. That is, consumers may not have made great changes in the way they use existing appliances, but the rate of increase in ownership/use of appliances is slowing. Indeed, examination of energy intensities based on heat, hot water or cooking per house or electric appliance electricity per income show marked retardation or cessation in the growth that was so prominent before 1972.

What about appliance energy intensity? As noted above, intensities are difficult to measure so we often settle for annual energy use, a quantity that combines lifestyle with intensity. We show some estimates of average annual electricity use per appliance for several countries (Table 3). We separate obligatory electrical uses--motors, lights--from low-temperature heat applications provided by appliances in Table 2. The data in Table 3 are only rough estimates. Nevertheless, they indicate some agreement among countries. High energy use for washers, for example, may be explained by the fact that some washers produce their own hot water electrically, while others, as is the case in the U.S., take hot water from central tanks. We found widespread use of "point of use" or "instant" water heaters using gas or electricity in Japan, England, France, Italy, and Germany, but we have found no careful study of the differences in efficiency coupled with differences in habits due to around this interesting technology. Thus we must refrain from any comments on intensity here.

Future Residential Energy Demand

Energy prices are now rising, often spectacularly. In Japan, for example, residential electricity prices hit ten U.S. cents/kWh in 1978: they are rising in every other country, though more slowly in Sweden and Canada than elsewhere. However, these prices often fell, in real or even in nominal terms, in nearly every country between 1960 and 1972. Subsidies of certain fuels (kerosene or gas in Japan, electricity in Italy) are disappearing if not already gone; all countries have felt the 1979/1980 OPEC price hikes and the increases in the cost of all forms of base load electric power. Only occasionally are there noticeable decreases in energy prices, not all of which are shown here (e.g., natural gas in England and oil and gas in resource-rich parts of Canada). What economists and engineers alike expect, therefore, is increased interest in technologies that use energy more economically in the home. These should be observable as data from 1979 and 1980 become available. Preliminary analysis suggests that 1978 energy intensities were somewhat lower than those before the oil embargo. The most dramatic changes in consumption, however, arose after 1978. Examining the changes in consumption since 1973 will form an important part of our FY 1981 work.

CONCLUSIONS

What tentative conclusions do we read from these preliminary considerations? First, we repeat our observation that the rapid rise in fuel and particularly electricity use appears to be caused by rising incomes and increased ownership of energy-using devices. But these devices are saturating even as incomes continue to rise. Hence, we expect considerably less growth in energy use relative to incomes in the future.

Second, there appear to be several levels of energy/electricity use per household or per capita. Comparison across incomes suggests that electricity prices in particular, which seem to vary more than fuel prices, are extremely important determinants of consumption. New appliance costs are also important, but are at this time beyond our study scope. It is no surprise, however, that the Swedes and Canadians consume the most electricity for appliances in both an absolute sense and relative to income. These countries enjoy the lowest electricity prices.

A related conclusion from the data available to use so far is the clear departure from pre-1972 growth patterns. While space-heating use has decreased somewhat in all countries, particularly when the increase in central heating since the embargo is counted, appliance energy use and, in some countries, energy consumed for hot water and cooking has not grown as fast as before. Some of this change is coincidental to the embargo and arises because key uses, such as hot water or refrigerators, have approached saturation.

The prominence of Swedish (and to a certain extent Canadian) low heat losses is not clear from this comparison, because we have not disaggregated space-heating by dwelling type or age and presence or absence of central heating. Available data, however, appear to make this possible for some countries, and measurements of actual groups of homes are available to us from each country studied. But the levels of saturation of central heating in most countries are still growing, suggesting that here space-heating needs will continue to grow, though at a reduced rate. In the future, we hope to include in our survey data that show the space-heating needs of typical new centrally heated homes built before and after the institution of new building norms ushered in after the 1972 oil embargo.

Because the use of electricity for heating may arise out of deliberate government policy, we find it crucial to separate this use, which is growing in some countries, from other uses of electricity. In Sweden, electric heating comprises a major part of the growth in use between 1972 and 1979. Growth in electric heating has also been dramatic in France.

One issue that arises when aggregated data are examined is how to count the resource energy consumed by electric heat. Our scheme, which treats each kind of use and energy source separately, at least in the initial analysis, avoids that problem. In future work we will try to separate the components of growth in each energy source.

Now that most families have acquired the means to use energy for the most important amenities (cooking, hot water, and space-heating using electricity, gas, or liquid fuels; refrigeration, TV, washing devices, minor appliances) conservation need not be seen as a threat to the acquisition of appliances. The prospects for savings based on replacement of inefficient devices with new ones are somewhat bleak until the stock begins to be replaced. The time period for appliances is short; for houses it is very long. We find great room for improving efficiency, even "major appliances" in Europe that are small by U.S. standards.

Our work thus far leads us to certain important ideas about the interaction of consumer behavior and energy use. First, there is an enormous variation in energy use per family for a given end use, a variation too large to be explained only by technology. We suggest that behavior--the way people use hot water, their preference for frozen rather than fresh foods--plays a key role here. But much remains to be quantified.

PLANNED ACTIVITIES FOR FY 1981

In FY 1981 we will perform an econometric analysis of the factors that have influenced consumption during the period of rapid growth (through 1975) and subsequently.

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