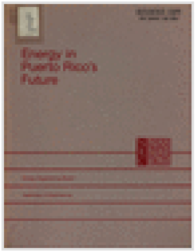

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Energy in Puerto Rico's Future

Final Report
of the
Committee on Future Energy Alternatives for Puerto Rico

Energy Engineering Board
Assembly of Engineering

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1980

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering and the Institute of Medicine.

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Office of Energy/Puerto Rico
Minillas Governmental Center
North Building, Office P, Stop 22
P.O. Box 41089, Minillas Station
Santurce, Puerto Rico 00940

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While the thirteen members of the Committee on Future Energy Alternatives for Puerto Rico are solely responsible for this report, many others contributed information and analyses. The committee expresses appreciation to all the individuals whose efforts furthered its work. In particular, the committee commissioned a number of papers by contractors and consultants; a list of whom is printed as Appendix A of this report.

Staff officers Duncan M. Brown and H. Kurt Strass worked closely with the committee, consultants, and outside contributors in producing the report. The staff and committee were ably supported by Karen Laughlin's administrative coordination.

CONTENTS

EXECUTIVE SUMMARY

Puerto Rico, like other areas of the world dependent on imported oil for energy, is faced with a serious challenge to its plans for continued economic and social development. An adequate response will require the progressive transformation of its energy sector, with significant repercussions on its entire economy. The central problems of adjustment to oil price increases arise from the fact that Puerto Rico's spectacular economic development since 1950, and the ways of life accompanying the present family incomes and living standards, took for granted the continuing availability of low-cost energy in the form of imported oil. Now the society must try to adjust to higher energy costs in ways that minimize negative impacts on economic activity and employment opportunities, reduce the downward pressure on living standards, and control the outward flow of income in payment for energy imports, while contributing to a smooth transition to an energy regime free from excessive dependence on imported oil. Solutions to Puerto Rico's energy problems could serve as examples of effective energy policies for other oil-importing tropical regions--a large fraction of the developing nations.

This committee's inquiry has revealed no panaceas, on either the supply or the demand side of the energy equation. No single low-cost energy source in sight on a scale sufficient to replace imported oil is in sight. Modest contributions can be made by a variety of domestic resources, which are becoming more competitive as the cost of imported oil continues to rise. They include small hydroelectric power projects, biomass converted to solid or liquid fuels, solar water heating, and some use of wind energy. For the medium term, some imported oil can be progressively replaced by cheaper imported coal, especially for generating electricity. The potential of solid and liquid fuels from biomass warrants especially intensive exploration. In the longer run, photovoltaic conversion of sunlight to electricity and ocean thermal energy conversion may make contributions. On the demand side, likewise, there are no easily achievable opportunities for conservation on a large scale, but in all sectors there are notable possibilities of improving energy efficiencies.

Making the most of these opportunities, and coordinating the responses to the inevitable economic and technical transitions in the Island's energy situation, may require novel institutional arrangements. The Puerto Rican government's executive branch should maintain a strong energy policy agency to bridge gaps between the energy responsibilities of other agencies and to foster smooth collaboration among such agencies on energy matters.

Puerto Rico, in dealing with its own energy problems, should grasp its opportunity to become an international energy laboratory, seeking and testing solutions especially appropriate to the oil-dependent tropical and subtropical regions of the world. The Island's geographical position and its established energy research and development facilities enhance this potential, which should be called to the attention of agencies and institutions with investments to make in accelerating development overseas.

FUTURE ENERGY DEMAND

This committee prepared two alternative projections of Puerto Rico's future energy demand, based on two assumed levels of economic activity. The projections are intended to serve as a basis for evaluating prospective energy technologies and conservation strategies. Puerto Rico's annual GDP growth rate for the higher level of activity (Case A) is projected at 4.0 percent in the period 1977-85, 3.8 percent in 1985-90, and 3.7 percent in 1990-2000. For the lower level (Case B), The corresponding rates are 2.8 percent (1977-85), 2.6 percent (1985-90), and 2.5 percent (1990-2000).

The projections disaggregate Puerto Rico's energy demand into three sectors: a residential sector, a transportation sector, and a combined industrial and commercial sector. The demand projections were broken down further as necessary for analysis, where the necessary historical data were available in sufficient detail. For each sector, the projections give demand estimates for fuel (virtually all petroleum) and electricity. These estimates reflect energy policies already in force or clearly foreseeable, but not additional measures, such as those recommended in this report.

Electricity Demand

Residential Demand

Residential demand for electricity in Case A is projected to grow at a 3.8 percent annual rate in the period 1977-85 and 3.5 percent in 1985-2000, compared with Case B's 3.0 percent (1977-1985) and 2.4 percent (1985-2000). With 1977 demand at 3.5 billion kWh, these growth rates yield demand figures for the year 2000 of 7.8 billion kWh (Case A) and 6.2 billion kWh (Case B).

Industrial and Commercial Demand

Projections of electricity demand in the industrial and commercial sectors reflect assumptions about the future prospects of several manufacturing categories and the combined commercial sector. The major such assumptions are as follows:

- Refining and petrochemicals.

  Case A - PPG Industries Caribe chloralkali plant will not reopen.
  Case B - In addition to Case A assumption, Oxochem, Puerto Rico Olefins, and Caribe Isoprene will not resume operations.

- Pharmaceuticals. Demand for electricity is estimated to grow at the following annual rates:
  Case A - 9.3 percent (1978-85); 6.5 percent (1985-2000).
  Case B - 6.5 percent (1978-85); 4.6 percent (1985-2000).

- Cement. Demand for electricity is estimated to grow at the following annual rates:
  Case A - 1.2 percent (1978-85); 1.7 percent (1985-2000).
  Case B - 0.8 percent (1978-85); 1.3 percent (1985-2000).

- Other Industry. Growth rates equal to growth in GDP assumed for Cases A and B.

- Commercial sector. Demand for electricity is projected to grow at the following annual rates:
  Case A - 3.4 percent (1978-2000).
  Case B - 2.4 percent (1978-1985); 2.2 percent (1985-2000)

The resulting projected aggregate electricity demands in the industrial and commercial sectors for Case A are 2.4 percent (1978-85) and 3.4 percent (1985-2000). The corresponding rates in Case B are 1.0 percent (1978-85) and 2.3 percent (1985-2000). This yields total electricity demand estimates for the industrial and commercial sector in the year 2000 of 14.8 billion kWh in Case A and 11.4 billion kWh in Case B.

Total Electricity Demand

The projected total electricity demands for Puerto Rico are as follows:

- Case A - 13.6 billion kWh (1985) and 22.6 billion kWh (2000) (respectively about 20 percent and 100 percent increases over 1977 sales).

- Case B - 12.5 billion kWh (1985) and 17.6 billion kWh (2000) (respectively about 11 percent and 57 percent increases over 1977).

The Puerto Rico Electric Power Authority forecasts 1985 electricity generation (which exceeds demand by about 15 percent, due to various losses) at 17.0 billion kWh. The corresponding values for 1985 in the projections presented above are 16.0 billion kWh in Case A and 14.7 billion kWh in Case B.

Fuel Demand

Transportation Demand

The transportation sector in Puerto Rico is dominated by the automobile. The rate of growth in gasoline sales averaged 10 percent per year in the five years prior to 1973, and has averaged 3.5 percent per year since then. In the projections, the expected increase in the number of vehicles is more than offset by an increase in fuel efficiency and a decrease in average vehicle-miles driven, so that gasoline sales drop 4 percent in Case A and 10 percent in Case B by the year 1985. Continued improvements in automobile efficiency through the year 2000 offset the continued growth in the automobile fleet, so that in Case A gasoline demand grows at less than 1 percent per year between 1985 and 2000, reaching a level only 8 percent higher than 1977 demand. In Case B, gasoline consumption by automobiles levels off at 1985 values for the rest of the century.

Industrial and Commercial Demand

Industrial and commercial fuel consumption is assumed to grow at an annual rate one percentage point lower than the growth rate in GDP.

Overall annual rates in Case A are 3.0 percent to 1985 and 2.7 percent between 1985 and 2000. The corresponding rates in Case B are 1.8 percent and 1.5 percent. This yields annual consumption in the year 2000 of 29.1 million barrels of oil in Case A, and 22.2 million barrels in Case B.

Total Fuel Demand

Excluding petrochemical feedstocks, Puerto Rico's oil imports are projected at 123 million barrels (Case A) and 118 million barrels (Case B) in 1985, and 159 million barrels (Case A) and 137 million barrels (Case B) in 2000. Internal consumption of petroleum is projected to increase to 63-68 million barrels per year by 1985 and to 81-102 million barrels in 2000, from the current level of 59 million barrels. Even at current prices for crude oil, that could imply annual oil import costs well in excess of 2 billion dollars by the year 2000.

THE OIL REFINING AND PETROCHEMICAL INDUSTRIES

In examining the industrial use of energy in Puerto Rico, this committee found the refining and petrochemical industries to be by far the largest industrial consumers of energy. For this reason, the committee investigated the outlook for these industries especially thoroughly, in terms of their likely impacts on future energy demand. The committee did not make recommendations about development of these industries, but did reach several conclusions about their implications for energy use. These are summarized below.

Refining

Refining operations on the Island should be able to supply both local and mainland markets profitably in the future. There are, however, two problems in this regard:

- The Jones Act, which requires that goods shipments between U.S. ports (including those in Puerto Rico) be made in U.S.-registered ships, has increased the cost of transporting oil products to the mainland. The committee believes that the best way to offset this disadvantage would be on outright exemption for all products refined in Puerto Rico. If such an exemption is unavailable, the Puerto Rican government should apply to Congress for a subsidy sufficient to offset the Jones Act disadvantage relative to the major Caribbean competitors.

- Securing adequate supplies of crude oil at a reasonable cost may be a problem, as it is in other oil-importing regions. Improvements in the reliability of the procurement system should be undertaken now to offset this disadvantage.

Puerto Rican refineries must look to three principal markets in the future: on-island fuel consumption, sales to Puerto Rican petrochemical producers, and mainland sales of refined products. Island refiners cannot take for granted protected markets either at home or on the mainland. Refiners in the Caribbean and Mexico, and even in Europe, are possible sources of competition.

Petrochemicals

The competitive position of the Puerto Rican petrochemical industry with respect to mainland manufacturers should improve as the price of domestically produced oil rises to world levels. Power and transport cost differentials are unlikely to constitute significant cost penalties.

Aromatics production is likely to remain profitable, with the prospect of modest expansion in line with demand.

Chloralkali production is not likely to be resumed in the foreseeable future. Artificial market advantages due to electricity rate subsidies have been ended.

Olefins, especially ethylene, and olefin derivatives raise crucial problems for petrochemical production. The Puerto Rico Olefins (PRO) facility, which has been shut down, could be operated profitably if its potential output of ethylene were matched by a corresponding demand in downstream processing units. Closing the chloralkali plant threatens to reduce demand for ethylene by halting production of vinyl chloride, and existing units provide little demand for ethylene. Reopening the PRO facility will require investment in at least one major ethylene-consuming facility.

Downstream operations, such as plastics and synthetic fiber production, are unlikely to receive major new investment. These operations depend more on local markets than on proximity to raw materials; their expansion will be based on demand growth in Puerto Rico.

Energy Demand

Projections of future energy demand for refining and petrochemical manufacture should be based on the following assumptions:

- Refinery production will increase slightly, to meet additional demand for refined products in Puerto Rico.

- Aromatics production will increase at about the same rate as total U.S. demand.

- The PPG Industries Caribe chloralkali plant will remain closed.

- Further balanced development of the petrochemical complex will require the reopening of the Puerto Rico Olefins ethylene cracker.

For utility planning purposes, these assumptions imply that sufficient electric power generating capacity to support full operation of the Puerto Rico Olefins ethylene cracker should be kept available. Any change in this outlook should be anticipated far enough ahead of demand to adjust operations accordingly.

THE ELECTRICAL GENERATING SYSTEM

The Puerto Rico Electric Power Authority operates a large, sophisticated electric supply system and is the third largest publicly-owned electric utility in the United States (outside of federal agencies). It accounts for close to 40 percent of the Island's energy consumption and is thus the prime factor in any examination of Puerto Rico's energy situation.

Nearly four decades of extraordinarily rapid growth in this predominantly oil-fired system were sharply interrupted in 1974. This dramatically altered the utility's financial and operational conditions, raising the need for reassessment by its planners and administrators. The committee offers several recommendations, summarized below.

Maintenance and Reliability

To improve the reliability of electrical service in Puerto Rico, PREPA should make a concentrated effort to improve the maintenance and availability of all steam-electric generating facilities, especially the four large units at Aguirre and South Coast.

So that generating capacity can be more smoothly and rapidly replaced when one of the larger units fails, more quick-response generating capacity should be made available by operating the large units slightly below full capacity and refurbishing some gas-turbine generating units. In addition, fast-acting under-frequency relays should be installed to shed noncritical loads immediately in case of loss of generation, so that priority of service can be given consumers for whom a loss of power has severe economic or safety consequences.

To improve the reliability of individual units, PREPA should adopt a "unit overall" maintenance schedule (under which every steam generating unit would be shut down every three to five years for inspection, routine repairs, and overhauls). This would replace the present "component overhaul" schedule, under which each major component is overhauled separately, so that every large unit is shut down for several weeks each year.

PREPA also should do disassembly work three shifts a day, seven days a week, whenever a unit is shut down for overhaul, so that the overhaul job can be assessed as quickly as possible. The Authority's maintenance procedure should require that rotating elements be opened for inspection in seven days or fewer.

Adding New Generating Capacity

The next large addition to PREPA's base load generating capacity must be fired with coal, supplies of which are less expensive and in the long run more secure than those of oil, which now fuels 99 percent of the system's generation. Added hydroelectric capacity, as well as a variety of less conventional alternatives such as solar and wind-powered generation, will make contributions in this century, but cannot obviate the need for a large conventional generating unit in the 1980's.

The committee reaffirms the conclusion in its interim report that the nuclear option should be preserved as a possible component of Puerto Rico's future electric power system. However, considerations of both scale and timing rule it out for the next major addition to the Island's generating capacity.

The committee concludes, on the basis of these and such other considerations as the likely growth in load, that the Electric Power Authority should continue on a course that would permit a new coal-fired, 300 megawatt unit to be brought on line by 1986 if needed.

Financing

To improve internal cash generation, which in recent years has rarely been large enough to cover even routine construction expenditures, electricity rates should be increased enough to raise about $60 million (in 1979 dollars) per year, in addition to increases needed to cover rising fuel, labor, and operating costs. During the fiscal year ending June 30, 1979, PREPA had to borrow $69 million merely to operate and make routine capital investments. The outlook for fiscal 1980 shows no improvement. Net borrowings are projected by PREPA at $104 million, again without major capital additions.

ENERGY CONSERVATION OPPORTUNITIES

Puerto Rico is subject to many of the same incentives to conserve energy as the mainland, in general more intensely than most areas of the mainland. Strong energy conservation measures will be essential to sound economic growth and assured energy supply, in Puerto Rico as elsewhere in the oil-consuming world.

The most significant opportunities for energy conservation policy in Puerto Rico are probably in transportation planning. A dual policy of improving public transportation and imposing penalties on inefficient use of automobiles can have large benefits at fairly reasonable cost.

In buildings the opportunities are not so great, because Puerto Rican homes do not generally use much energy by mainland standards. A number of simple conservation measures can be undertaken by the owners and occupants of residential buildings to increase comfort and lower air-conditioning loads, but only the simplest are generally cost-effective at current electricity rates. Commercial and industrial buildings also offer modest opportunities for savings. The residential rate subsidy for households consuming less than 425 kWh per month offers an especially clearly inaccurate cost signal to consumers, and thus an inadequate incentive to conserve. Reform of this subsidy deserves a high priority.

Electricity rate reform can be an effective instrument for energy conservation. Most of the Puerto Rico Electric Power Authority's rates are charged under declining block structures, which give consumers a false picture of the cost of service. Since the cost of service in most cases rises with increasing consumption, such structures should be abandoned.

Cogeneration of electricity and useful heat offers the potential for substantial energy savings on the Island, in industry and elsewhere. The refining, petrochemical, and sugar industries hold most of the potential for cogeneration. Resort hotels are also serious candidates. The planning and institutional barriers to cogeneration, however, are imposing.

RENEWABLE ENERGY SOURCES

Puerto Rico appears to offer especially favorable conditions for several renewable energy technologies. This committee appraised the prospects of the main candidates in this field. Its findings, summarized below, should not be taken as predictions of the future, although they do indicate the probable relative priorities to be accorded these technologies in the near term. Unexpected technical advances could permit higher rates of application than those given here, and the Puerto Rican government should remain alert to progress in research and development.

Biomass energy cropping, based on the sugarcane industry, and solar water heating appear to be the most important renewable energy sources for the medium term; between them they could displace perhaps percent of Puerto Rico's electricity needs by the year 2000, and as much as 5 percent of the Island's fuel consumption. Lesser contributions may be made by wind-powered electricity generation, ocean thermal energy conversion, hydroelectric power, and solar photovoltaic energy conversion.

Biomass

Biomass cropping, to contribute as much as 10 percent of the Island's electricity, would probably have to use about as much land as the present sugarcane industry, or 90,000 acres. Such an industry, when mature, would likely produce both bagasse as a fuel for electric power plants and ethanol as a beverage and motor fuel. The engineering problems are fairly straight-forward, and the economics appear to warrant further evaluation.

We recommend that the Puerto Rican government obtain an independent land-use analysis to help determine the best use of Puerto Rican agricultural resources, with biomass cropping as one of the possibilities. To provide data for this study, a qualified engineering firm should be retained to develop a plan for a pilot-scale facility, in enough detail to identify the technological problems and estimate the costs and energy balances of a full-scale system.

If the results of the studies are encouraging, the Puerto Rican government should seriously consider establishing a pilot 10-20 megawatt generating plant, with the intensively managed cane fields needed for year-round operation (about 1,750-3,500 acres).

Further funding of fermentation and distillation research at the Agricultural Experiment Station's Rum Pilot Plant should be aimed at more efficient, less costly methods of manufacturing fuel ethanol.

Solar Water Heating

By the year 2000, the contribution of solar water heating might displace the equivalent of about 1 percent of total electricity generation; the contribution to industrial heating will likely be greater, with savings amounting to almost 1 percent of the Island's fuel consumption. Collectors for the Puerto Rican climate could be simple and inexpensive compared to those that would be used in most of the mainland.

High priority should be given to the formulation and maintenance of a program of financial and other incentives, which should be revised as the economics of solar water heating change in the coming decades. The present high interest rates suggest that special low-interest financing would be especially helpful.

Wind Energy

Wind energy can supply perhaps 1 percent of Puerto Rico's electricity by the year 2000, if the large wind turbines now under development become commercially available by 1985 and a number of practical sites can be identified.

Data on the winds in Puerto Rico are very limited. A detailed survey could identify favorable sites. Instruments should be installed at some of the most promising sites to obtain wind velocity data at elevations appropriate to modern wind turbines.

Hydroelectric Generation

The hydroelectric contribution, if expanded by adding new generating facilities and reviving capacity lost during the last decade, would amount to about 1 percent of the estimated demand in 2000. However, the electric power thus produced represents a direct displacement of very expensive fuel oil, so a vigorous effort to expand hydroelectric production is likely to be cost effective in the long run.

On this basis we support the action of PREPA, which has begun to study the feasibility of reactivating some retired capacity. We also recommend that the feasibility of adding additional hydroelectric capacity be reviewed in light of recent increases in world oil costs.

Photovoltaic Systems

In this committee's view, given the uncertain prospects of meeting the federal cost reduction goals for photovoltaic systems, it would be wise to plan on the basis of at least a five-year delay, so that large scale photovoltaic installations would not become commercially feasible unitl nearly 2000 at the earliest. Under this assumption photovoltaic systems will make no appreciable contribution to Puerto Rico's energy needs before the year 2000. Since Puerto Rico offers favorable conditions for applying such systems if and when major breakthroughs take place, technical progress should be monitored, and Puerto Rico should participate in the federal experimental program.

Ocean Thermal Energy Conversion

The OTEC concept is at an early stage of development and must be regarded as expensive and risky at present. With other forms of solar energy the uncertainties are mainly whether cost goals can be met; with OTEC there is the distinct possibility that little net usable power may be produced. If OTEC proves commercially viable it will

1 THE SETTING AND THE ISSUES

Puerto Rico, like other areas of the world dependent on imported oil for energy, is faced with a serious challenge to its plans for continued economic and social development. An adequate response will require the progressive transformation of its energy sector, with significant repercussions on its entire economy.

Compared with many developing countries that, like Puerto Rico, lack fossil fuels and water power, the Island is more industrialized and enjoys a much higher standard of living. Its per capita energy consumption is greater than that of Italy, for example, and much greater than that of any oil-importing developing country. Unlike most industrial nations, which use varying proportions of coal, natural gas, water power, and nuclear energy, Puerto Rico depends almost totally on oil to meet its energy requirements. The impact of sharply higher oil prices is correspondingly severe.

Puerto Rico, like New England, possesses no proven reserves of oil, gas, or coal and only modest resources of water power. It has the advantage over New England of not requiring fuel for space heating, but the disadvantage of an isolated electric power system that is too small at present for the introduction of nuclear power and is unable to draw on the output of neighboring systems. On the other hand, Puerto Rico's location in the tropics could facilitate the use of solar energy in its various directly and indirectly exploitable forms.

The central problems of adjustment to oil price increases arise from the fact that Puerto Rico's spectacular economic development since 1950, and the lifestyles accompanying the rapid improvements in family incomes and living standards, took for granted the continuing availability of low-cost energy in the form of imported oil. Cheap energy, however, was not the major factor in a large part of the industrial expansion that spearheaded the Island's development. On the contrary, most industrial employment in Puerto Rico has been in manufacturing areas that rely on available labor but are not especially energy-intensive. In fact, before 1973 industrial energy prices were somewhat higher in Puerto Rico than in competing mainland regions of the United States, especially those with cheap natural gas. The one outstanding exception--very important in terms of the value of its output but less so in terms of employment--was the oil refining and petrochemical complex, based on an artificial price advantage over competitors due to quotas on oil imports to the mainland, which ended in 1974. For that sector, as discussed in Chapter 4, the realistic challenge for the rest of this century is to ensure survival at or near its present scale; expansion beyond basic improvements in the product balance of the petrochemical complex is unlikely.

For the rest of the economy--other lines of industry, commerce, transportation, tourism, agriculture, construction, and household activities--the challenge is adjusting to higher energy costs in ways that minimize their negative impacts on economic activity and employment opportunities, reduce the downward pressure on living standards, and control the outward flow of income in payment for energy imports. The goal is a smooth transition to an energy regime that does not rely unduly on imported oil. Effective solutions to Puerto Rico's energy problems could serve as examples of effective energy policies for other oil-importing tropical regions--a large fraction of the developing nations.

Our inquiry into energy alternatives for Puerto Rico has revealed no panaceas, on either the supply or demand side of the energy equation. There is in sight no single low-cost energy source on a scale sufficient to replace imported oil by the year 2000. However, a variety of domestic resources, becoming newly competitive as the cost of imported oil rises, can make modest contributions. These include small hydroelectric projects, biomass converted to solid or liquid fuels, solar water heating, and possibly some use of wind energy (Chapter 7). Biomass conversion appears to warrant especially intensive further research. In the longer run, contributions may be made by photovoltaic conversion of sunlight to electricity and by ocean thermal energy conversion. Puerto Rico offers especially attractive conditions for the latter, if the technology can be made a net energy producer without inordinate capital costs.

On the demand side, there are no easily exploitable opportunities for conservation on a large scale, but there are notable possibilities for making the basic problem of higher energy costs more manageable through improved efficiency in energy production and use. These improvements, outlined in Chapter 6, apply to the four major sectors of energy consumption--households, transportation, commerce, and industry--and include some possibilities for cogeneration of electricity and useful lower temperature heat at high efficiency.

Puerto Rico will of course share in benefits from national energy development that makes use of the large continental resources of coal, oil shale, and heavy oils. Puerto Rico will also be a direct participant in any national policies that promote direct or indirect use of solar energy and encourage or require conservation. The continuing uncertainties concerning such measures--their application, the timing and character of their results, and their relative costs--are such that Puerto Rico would be well advised to make resiliency a central feature of its energy policies. A number of options should be kept open wherever possible, and irrevocable commitments should not be made prematurely, though Puerto Rico cannot await national action before moving to ease its own energy problems.

The Puerto Rican economy is closely integrated with that of the United States mainland through trade, finance, investment, tourism, and governmental transfer payments. Puerto Rican economic conditions, and the related demands for energy, are heavily dependent on the economic prospects for the nation as a whole, and Puerto Rican energy policies are similarly intertwined with those at the national level. This committee has based its work on judgments of plausible expectations concerning national economic and energy developments, and has concentrated its attention on policy areas unique to Puerto Rico or within the direct control of the Puerto Rican authorities.

To provide a basic quantitative framework, within which policy judgments can be made and priorities set, the committee prepared a range of projections of energy requirements in the years 1985 and 2000, based on energy consumption in each economic sector in 1977 (Chapter 3). These projections reflect an awareness that Puerto Rico's future energy requirements will be influenced by a wide range of economic, social, and political decisions that will affect population size, migration (both in and out), labor force participation, housing, agricultural and industrial investment and development, and tourism.

Energy policies should be designed so that they do not unduly constrain economic development that is otherwise feasible and desirable. Some constraints resulting from the higher costs of imported oil are unavoidable. At the same time, if investments in alternative sources of energy or in energy conversion to electricity or liquid fuel are too far ahead of demand, they could absorb a large fraction of the Island's available capital and impose excessive and unnecessary constraints on other economic activities. Delicate judgments will be required to gear energy supply capacity to demand prospects. That principle is of special importance in regard to electricity supply, where long lead times are involved in planning and constructing new capacity and where capital requirements account for a large portion of Puerto Rico's bond market financing (Chapter 5).

The evolution of Puerto Rico's economy over the next two decades is exceptionally difficult to forecast with confidence. Structural changes already underway will affect the nature of further industrialization, the future of agriculture, the size and character of the labor force, and other aspects of the economy. The twenty years from 1980 to 2000 are unlikely to be a repetition of 1955 to 1975, the era of Puerto Rico's most rapid economic growth. The energy situation itself is one important source of change, since the oil refining and petrochemical industries have lost their favored market positions. The full application of mainland minimum wage laws could discourage some categories of industrial investment. Identifying and attracting industries that combine desirably low energy consumption, high value added, and requirements for substantial numbers of skilled and semi-skilled workers will require special efforts.

Perhaps the largest source of uncertainty concerns the economic prospects of the mainland United States, which is the principal market for Puerto Rico's industry. In the near future, some degree of economic recession, perhaps with a modest slackening of inflation, is forecast, but expectations of its magnitude and duration are very diverse. In the longer run, the combination of demographic slowdown, reduced productivity growth, environmental and regulatory constraints, anxiety over inflationary pressures, and much higher energy costs is expected to produce slower overall economic growth than in the post-war decades. In that event, Puerto Rico will face an even greater challenge in finding industrial specialties with larger than average opportunities for expansion, so as to maintain its post-war record of overall and per-capita growth rates higher than those of the mainland.

Another important variable is the size of the labor force in Puerto Rico--a function of population growth, net migration, and degree of participation. Population growth is still higher than on the mainland, although falling rapidly. However, the greatest uncertainties concern the likelihood of net migration either to or from the Island. High unemployment has been a chronic feature of the Puerto Rican economy and a central concern of development policy. If slower mainland growth reduces employment opportunities there, the pressures on Island labor markets will become more severe, with potential repercussions on public policies and ultimately on energy needs.

In pointing out this wide range of uncertainties, the committee is not evading its mandate to survey the energy alternatives facing Puerto Rico over the rest of this century and to recommend actions in the energy sector. Our energy demand projections are based on explicit or implicit assumptions concerning economic developments and policies outside the area of energy. It is clearly not the function of this committee to develop overall economic and social plans and programs for Puerto Rico. Nor is it our function to recommend basic energy policies in the United States that would have desirable impacts on Puerto Rico. Without losing sight of these broader interconnections, however, we have tried to identify energy policies that can be pursued by the Government of Puerto Rico and that would contribute most effectively to Puerto Rico's continued economic and social progress.

The analysis and recommendations in the following chapters cover all the principal components of Puerto Rico's energy problems: demand projections; the oil refining and petrochemical industries; the electric power system and conventional fuel options; energy conservation opportunities; and renewable energy sources. In addition to its findings in these areas, the committee wishes to call attention to two institutional matters that transcend the specific energy supplying or consuming sectors.

The first of these matters is the importance of a strong energy policy agency at a high level in the executive branch of the Island's government. In the coming transition to new forms of energy supply and use, many issues will fall outside the normal responsibilities of established agencies or require novel kinds of collaboration among agencies. Examples include multi-purpose use of reservoirs, production of electricity or fuel alcohol from biomass, arrangements for cogeneration of electricity and process heat or commercial refrigeration, and improved energy efficiency in cooling buildings and in transportation. In addition, a flexible technological response to higher energy costs requires active monitoring of energy research and development. For these reasons, the committee believes it highly desirable that the Office of the Governor maintain a technically qualified energy agency as a permanent feature.

The second recommendation concerns the special opportunities for energy research and development related to Puerto Rico's geographical situation. Many developing countries share with Puerto Rico both the problem of dependence on increasingly expensive imported oil and conditions of soil and climate that appear especially conducive to the direct or indirect use of solar energy. At the same time, Puerto Rico possesses a university of high quality and a strong base for both academic and commercial research and development, including ready access to the corresponding resources on the mainland. The Island should consequently be an especially desirable site for research on energy supply and conservation opportunities appropriate to tropical conditions, which could be of benefit to neighboring Caribbean and Latin America countries and also to many parts of Asia and Africa. The committee believes that these special advantages should be called to the attention of agencies and institutions concerned with accelerated development overseas, such as the Agency for International Development, the World Bank, and the Inter-American Development Bank.

2 THE HISTORICAL BACKGROUND

Until the 1950's, the Puerto Rican economy was based on agriculture. In 1955, manufacturing surpassed agriculture as an income generator as a result of the Puerto Rican government's industrial incentives program, "Operation Bootstrap." Under this program the Puerto Rican government offered long term exemptions from income, property, and other local taxes to companies establishing operations on the Island. These inducements, coupled with exemptions from federal corporate income taxes, wages appreciably lower than on the mainland, and an active promotional campaign, stimulated a remarkable growth in the manufacturing sector and in the Island's economy as a whole. Between 1950 and 1978, Puerto Rico's gross domestic product (GDP), measured in constant dollars, increased more than fivefold, with an average annual growth rate of 6.0 percent, compared to a rate of 3.6 percent for the United States as a whole. In 1950, agriculture accounted for 18.2 percent of the GDP and manufacturing for only 16.5 percent; by 1978, the corresponding shares of the much larger total were 2.8 percent for agriculture and 34.7 percent for manufacturing.[1]

This extraordinary expansion was slowed in 1974 and temporarily reversed in 1975, when economic growth was negative for the first time in Puerto Rico's modern history. The setback was in part due to the OPEC-directed rise in the world price of oil, which eliminated the oil cost advantage enjoyed by Puerto Rico's oil refining and petrochemical industries, and in part a reflection of the recession on the United States mainland, which curtailed tourism and Puerto Rican exports. These factors were aggravated by a decline in the construction industry due to overbuilding in prior years. A modest economic recovery took place between 1976 and 1979, but with growth rates substantially below the record levels of the late 1960's and early 1970's.[1]

In 1966, the Governor of Puerto Rico asked the National Research Council to undertake a broad study of the Island's options in its struggle to create a prosperous society, with emphasis on the use of science and technology. The primary conclusion of the study, published in 1967,[2] was that Puerto Rico must commit itself to increased productivity. Such a commitment, according to the report, would require developing a skilled work force, introducing new production-increasing innovations, and shifting to new production areas.

These recommendations reinforced already existing trends, from labor-intensive to more capital-intensive industries. Impressive gains had been made in manufacturing, exports, and employment during the 1950's and 1960's. In the manufacturing sector, the shares of such traditional industries as food processing, clothing, and furniture manufacture fell sharply as the manufactures of professional and scientific instruments, electrical machinery, metal products, petrochemicals, pharmaceuticals, and petroleum products assumed dominance. By 1978, these six industries accounted for 56 percent of total manufacturing output (27 percent in pharmaceuticals alone), compared with only 23 percent in 1960. Labor-intensive industries such as food processing and the manufacture of clothing; textiles; and leather, wood, and tobacco products were still important, but their share had fallen from 60 to 32 percent of manufacturing output and from 70 to 52 percent of employment in manufacturing.[1]

PETROLEUM REFINING AND PETROCHEMICAL INDUSTRIES

Although the petroleum refining and petrochemical industries contributed a little less than 10 percent to Puerto Rico's gross domestic product in 1978, they consumed more than 20 percent of the Island's electricity.[1,3] They are thus very important influences on Puerto Rico's future energy demand. The outlook for these industries and its implications for energy demand are discussed in Chapter 4.

The establishment of these industries in Puerto Rico depended on two major competitive advantages. The first was access to feedstocks at low costs. Until the 1974 OPEC price rise, foreign crude and unfinished oils (naphtha) were less expensive than domestic supplies in the United States. Oil imports by mainland refiners were limited by federal quotas under the Mandatory Oil Import Program (MOIP). Naphtha for processing into petrochemicals generally could not be imported at all on the mainland. Any firm able to import these products outside the quotas therefore enjoyed a significant cost advantage. The federal government had amended the MOIP in 1965 to exempt Puerto Rico from these limitations. Puerto Rico thus could obtain crude oil at about $1.25 per barrel less than the mainland price, a cost advantage of about 30 percent.[4,5]

Special tax concessions were the other advantage a Puerto Rican location offered industry. The Puerto Rican government offered long term exemptions from income, property, and other local taxes to companies establishing operations in Puerto Rico. With the exemption from federal corporate income taxes accorded by Section 931 of the United States Revenue Code, this provided a very attractive investment climate.

Attracted by these incentives and encouraged by a strong United States economy, the refining and petrochemical industries in Puerto Rico expanded rapidly in the 1960's and early 1970's. About 60 percent of the fuels produced were consumed on the Island, but most of the petrochemicals were shipped to the mainland. In the peak year 1973-74, these two industries accounted for 13.2 percent of Puerto Rico's manufacturing output and 4.6 percent of manufacturing employment. By 1978, the share in output had been reduced to 9.3 percent, but the employment share had increased slightly to 5.0 percent.

The export of large amounts of basic petrochemicals was looked upon as a short term transitional phase in the growth of Puerto Rico's petrochemical industry. The long term plans of the Puerto Rican government and of the industry were to develop downstream facilities for processing these basic chemicals, ultimately into petrochemical-based consumer items. Downstream industries provide more employment per unit of output than basic petrochemical production and generally involve substantially more value added. Furthermore, downstream processing industries tend to raise fewer environmental problems than basic petrochemical facilities.

These operations were expected to be major stimuli to the Island's economy. However, after the 1973 embargo and the subsequent fourfold increase in the price of imported oil, the Puerto Rican cost advantage in refining and petrochemicals was lost. Foreign oil became more expensive than domestic oil, and the controlled prices of petroleum products sold in the U.S. market were below world market levels. Investment in these industries in Puerto Rico virtually ceased. The companies involved experienced grave financial difficulties, and several plants were closed.

Without help from the federal government, the Puerto Rican oil refining and petrochemical industries would almost certainly ceased operations. The principal federal actions were as follows:

- Inclusion of Puerto Rico in the entitlements program designed to equalize crude oil costs among all mainland United States refiners. (Although this program has accomplished its objective and crude oil costs with entitlements are essentially the same in Puerto Rico as those on the mainland, the Island's former cost advantage relative to the mainland has been lost.)

- Inclusion of naphtha imports into Puerto Rico in the federal entitlements program. (This only partially offsets the cost differential. As of December 1, 1978, Puerto Rico's petrochemical industry paid a raw material cost penalty of about $5.00 per barrel relative to the mainland.)[4]

- Waiver of import license fees of 21 cents per barrel on crude oil and 63 cents per barrel on naphtha.

A supplemental import fee of $2.00 per barrel was imposed by the federal government in mid-1975 but was discontinued at the end of that year. A similar $2.00-per-barrel fee on imports of crude oil and naphtha was then imposed by the government of Puerto Rico, with a rebate for products consumed off the Island. The fee was eliminated July 1, 1978. (This action reduced the cost of fuel oil to the Island's electric utility, which made a corresponding reduction in the fuel adjustment charge to its customers.)[3,5]

THE ELECTRIC POWER SYSTEM

The rapid growth in the Puerto Rican economy was accompanied by a corresponding increase in the demand for electric power. This demand was met by the Puerto Rico Electric Power Authority (PREPA, formerly the Puerto Rico Water Resources Authority, or PRWRA)--the government-owned utility company that produces and distributes virtually all electric power in Puerto Rico. PREPA has grown since its establishment in 1941 from a small system in which three-fourths of the power was produced by hydroelectric facilities to the third largest public power system in the United States (excluding federal agencies). Ninety-nine percent of PREPA's power is provided by oil-fired generating units.

Growth of Electric Generating Capacity

During the past four decades the production of electric energy in Puerto Rico, as shown in Figure 1, increased more than a hundred-fifty-fold. The average annual growth rate was about 14 percent until the sharp escalation in oil prices and U.S. recession in 1974-1975. Figure 2 compares the growth in generating capacity with the growth in annual peak load for the period 1935 through 1978. During most of this period, the WRA was able to provide enough new generating capacity to maintain a reserve margin of about 40 percent.

Also plotted in Figure 2 is a curve showing the growth in the Puerto Rican gross product indexed to the year 1950. The rate of increase of new capacity was more than twice the economic growth rate, showing that, as on the mainland, the society was becoming much more intensive in its use of electricity.

In the mid-1960's the rapid increase in electricity consumption and the expected continuation of rapid industrial growth induced the Puerto Rican authorities to begin a major expansion of generating

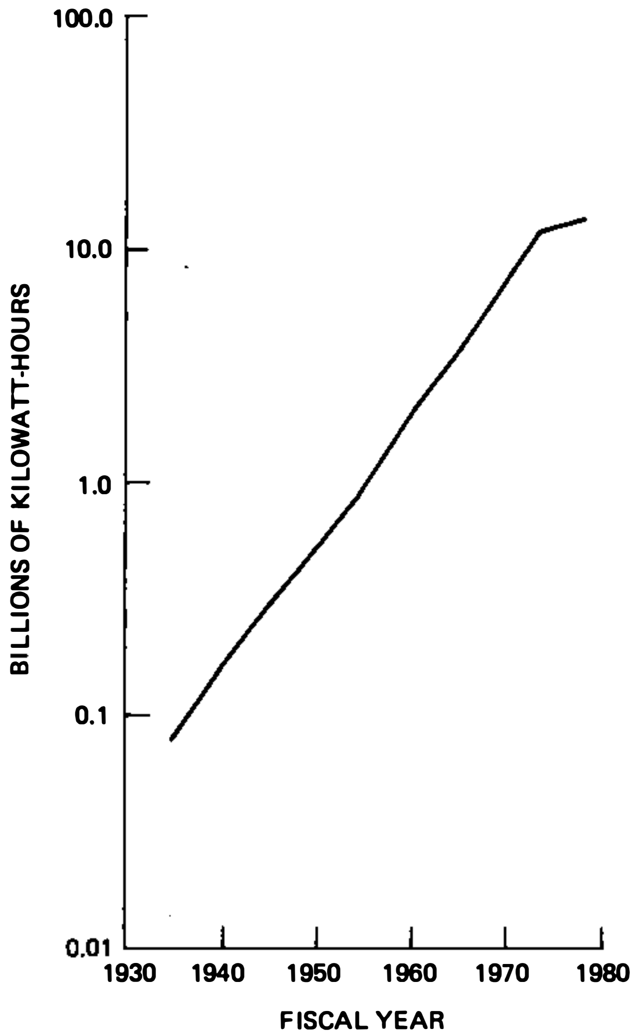


Figure 1 Puerto Rico Water Resources Authority electricity production, 1935-1978, in billions of kilowatt-hours per year (U.S. Army Corps of Engineers. 1977. Ponce Regional Water Resources Management Study. Appendix D: Technical Appendix, Part VI (Hydroelectric Power Potential). Report prepared for the Jacksonville District and the Government of Puerto Rico; Puerto Rico Water Resources Authority. October 1976 through December 1978. General Monthly Reports. Production Division. San Juan.)

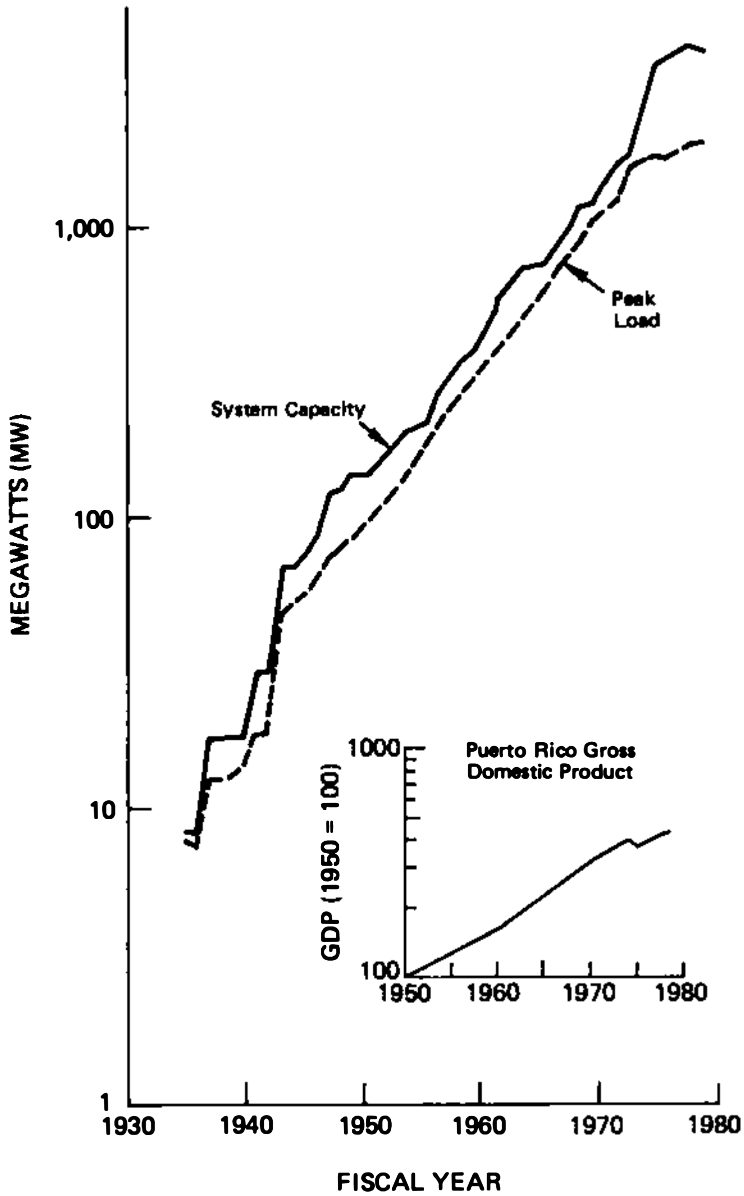


Figure 2 Puerto Rico Water Resources Authority total installed capacity and peak load, 1935-1978, in megawatts per year; Puerto Rican gross domestic product, in index form with 1950 value set at 100 (U.S. Army Corps of Engineers. 1977. Ponce Regional Water Resources Management Study. Appendix D: Technical Appendix, Part VI (Hydroelectric Power Potential). Report prepared for the Jacksonville District and the Government of Puerto Rico; Puerto Rico Water Resources Authority. October 1976 through December 1978. General Monthly Reports. Production Division. San Juan.)

capacity. This program included the construction of the four largest units in the Island's system, all oil-fired steam plants; South Coast units 5 and 6 (410 megawatts each) became operational in 1972 and 1973, and Aguirre units 1 and 2 (450 megawatts each) became operational in 1975. It also included two 300 megawatt combined-cycle units at the Aguirre site, which came on line in 1977.

The expansion program of PREPA also included plans for the construction of a 614 megawatt nuclear generating plant. A contract for this plant was initiated in 1970. It would have been the first major nuclear power plant in Puerto Rico and the first major plant not fueled by petroleum. (The utility had some operational experience with a small U.S. Atomic Energy Commission nuclear demonstration plant known as BONUS.)[6] Delays were experienced in obtaining a licensed site and the startup date was expected around 1980.

Unfortunately, the sharp rise in oil prices and the accompanying leveling off in electricity consumption occurred just as the expansion program was nearing completion. The oil-fired units were completed, but installation of the nuclear plant was deferred. Electricity consumption has increased only about 3 percent annually since 1975, and with the completion of the combined-cycle units in 1977 the total capacity of the PREPA system came to about 4,200 megawatts. The record peak load (September 1978) is 2,057 megawatts, giving the system a reserve capacity margin of more than 100 percent. (See Figure 2.)

Subsidies to Consumers

In 1967, as an attraction to major industrial customers, Puerto Rico enacted Public Law 82, under which PRWRA was authorized to negotiate special contracts at lower than standard rates.[4] These subsidies are financed from general revenues and are a charge on the Puerto Rican budget.[7] When the cost of fuel rose in 1974, the increased expense to the utility exceeded the available subsidy of $3.0 million. Accordingly, the contracts were adjusted to reflect the higher fuel costs, and fuel adjustment charges were added. Revenues, however, still fell short of costs in some cases. For example, the average special rate charged petrochemical plants was 2.66 cents per kilowatt-hour in 1978 (as compared to 5.14 cents per kilowatt-hour for other manufacturing industries).[1] The average production cost in 1978 was 2.82 cents per kilowatt-hour.[3] However, in 1979 only two Public Law 82 contracts remained in effect; these expire in 1981 and no new ones are planned.

Capital costs for rural electrification have been reduced through low interest loans from the federal Rural Electrification Administration. There is a small subsidy from Puerto Rico general revenues, amounting to about $2 million per year, for maintaining distribution lines in rural areas.

The largest subsidies for electricity were introduced in 1974 to offset the sharp increase in oil prices. For any residential customer using less than 425 kWh in any month, the rates exclude the fuel adjustment charge on the first 400 kWh. The difference is paid out of funds appropriated by the Puerto Rican government. About 70 percent of residential customers have qualified for this subsidy, which is automatically increased as the price of oil continues to rise. The record since the subsidy was introduced in mid-1974, and PREPA's most recent projections through 1985, are summarized in Table 1. The implications of this subsidy for energy conservation objectives and our recommendations for its reform are discussed in Chapter 6.

OVERALL ENERGY CONSUMPTION AND OIL IMPORTS

In addition to the electric power system and the oil refining and petrochemical industries, other sectors of the economy have experienced rapid growth in nonelectric energy consumption. The transportation sector is especially important in this growth; the number of licensed vehicles has grown very rapidly (Table 2).

These factors contributed to a sharp increase in overall energy consumption in Puerto Rico from 1950 to 1974. The essential facts are summarized in Table 3, along with a comparison of the energy intensities of Puerto Rico and the United States mainland. The same information is shown graphically in Figures 3 and 4. It will be noted not only that energy consumption in Puerto Rico grew with the industrialization of the Island and the increase in living standards, but also that the intensity of energy use in relation to gross domestic product also grew rapidly until the early 1970's. When allowance is made for the fact that space heating accounts for over 15 percent of total energy use on the mainland, it is indeed striking that the energy intensity of the Puerto Rican economy has risen so close to mainland levels, as shown in the last column of Table 3 and the upper curve in Figure 4.

Almost all of Puerto Rico's energy is now supplied by imported oil. Water power accounts for only one percent of the electricity--a smaller absolute amount than in the 1940's. Very small amounts of energy for sugar mills come from the burning of bagasse (sugar cane waste material). Solar contributions have been insignificant. The history of overall energy consumption is essentially the history of net oil imports--gross imports less exported oil refinery products.

Throughout the 1950's and 1960's, the world price of oil was stable in current dollars and falling slightly in real value. Quotations from Venezuela, the principal source of oil for Puerto Rico at that time--hovered between $2.50 and $3.00 per barrel. After 1971, a gradual rise took place, followed by the explosive quadrupling of world oil prices at the end of 1973.

The consequences for Puerto Rico are summarized in Table 4. Over the nine years 1968-77, the value of net oil imports rose from 1.7 to 14.6 percent of GDP. Further increases in world oil prices threaten to increase this percentage even more.

Table 1 Residential electricity subsidy and sales, 1975-1985

Year ending June 30	Amount of subsidy (thousands of dollars)	Residential electricity sales (thousands of dollars)	Share of subsidy in residential electric revenues (percent)
Actual			
1975	26,405	156,107	16.9
1976	32,403	177,979	18.2
1977	40,262	201,447	20.0
1978	48,177	226,040	21.3
1979	51,707	219,514	23.6
Projected			
1980	68,500	286,612	23.9
1981	79,500	321,396	24.7
1982	90,600	355,539	25.5
1983	102,900	392,773	26.2
1984	118,300	437,280	27.1
1985	135,700	486,951	27.9

Source: Donovan, Hamester, and Rattien, Inc. April 1979. Energy Data for Puerto Rico. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

Table 2 Licensed motor vehicles in Puerto Rico, compared with United States

Year	Puerto Rico			United States			Ratio of Puerto Rican vehicle concentration to mainland (percent)
	Numbers of vehicles (thousands)	Population (thousands)	Vehicles per thousand persons	Numbers of vehicles (millions)	Population (millions)	Vehicles per thousand persons	
1966	295.6	2,603	114	94.0	196.6	478	24
1967	327.5	2,630	125	96.9	198.7	489	26
1968	366.0	2,654	138	100.9	200.7	503	27
1969	419.0	2,688	156	105.1	202.7	519	30
1970	478.3	2,716	176	108.4	204.9	529	33
1971	534.8	2,746	195	113.0	207.1	546	36
1972	601.7	2,816	214	118.8	208.8	569	38
1973	681.6	2,912	234	125.7	210.4	597	39
1974	738.5	3,008	246	129.9	211.9	613	40
1975	773.7	3,121	248	133.0	213.6	623	40
1976	814.4	3,214	253	138.5	215.2	644	39
1977	830.4	3,319	250	143.8	216.9	663	38
1978	870.0	3,358	259	148.8	218.5	681	38

Source: Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

Table 3 Energy consumption and energy intensities in Puerto Rico and the United States, 1950-1977

Year	Puerto Rico				United States				Puerto Rico as percentage of United States	
	A Total energy consumption (thousands of metric tons coal equivalent)	B Per capita consumption (kilograms coal equivalent)	C GDP at 1954 prices (millions of dollars)	D Energy consumption per millions of dollars of GDP (tons coal equivalent)[a]	E Total energy consumption (millions of metric tons coal equivalent)	F Per capita consumption (kilograms coal equivalent)	G GNP at 1954 prices (billions of dollars)	H Energy consumption per millions of dollars of GNP (tons coal equivalent)[a]	Per capita consumption	Ratio of energy to GNP (GDP)
1950	1,126	507	844.1	1,334	1,114.0	7,316	318.4	3,499	6.9	38.7
1955	1,852	823	1,058.3	1,750	1,309.0	7,889	390.9	3,349	10.4	52.3
1960	3,448	1,460	1,487.4	2,318	1,476.5	8,172	439.8	3,357	17.9	69.0
1965	5,214	2,013	2,212.6	2,357	1,782.9	9,176	552.7	3,226	21.9	73.1
1966	5,974	2,280	2,382.2	2,508	1,903.4	9,684	585.6	3,250	23.5	77.2
1967	6,632	2,503	2,538.0	2,613	1,941.5	9,770	601.5	3,228	25.6	80.9
1968	7,565	2,833	2,688.3	2,814	2,061.7	10,272	627.8	3,284	27.6	85.7
1969	8,619	3,169	2,937.2	2,934	2,177.8	10,745	643.9	3,382	29.5	86.8
1970	9,033	3,317	3,180.1	2,840	2,257.9	11,020	641.8	3,518	30.1	80.7
1971	10,671	3,845	3,401.9	3,137	2,307.8	11,146	661.1	3,491	34.5	89.9
1972	11,327	3,952	3,652.1	3,102	2,426.2	11,617	699.0	3,471	34.0	89.4
1973	12,945	4,563	3,981.2	3,252	2,480.6	11,789	737.2	3,365	38.7	96.6
1974	13,572	4,729	4,059.6	3,343	2,406.6	11,359	726.9	3,311	41.6	101.0
1975	12,198	4,203	3,965.5	3,076	2,322.3	10,874	717.7	3,236	38.7	95.1
1976	12,355	4,208	4,166.9	2,965	2,473.4	11,497	759.9	3,255	36.6	91.1
1977	13,774	4,638	4,443.2	3,100	2,509.5	11,574	800.1	3,136	40.1	98.9
1978	14,015	4,664	4,672.0	3,000	2,502.1	11,374	835.2	2,996	41.0	100.1

[a]D = A x 1000 ÷ C; H = E x 1000 ÷ G

Source: Energy consumption totals and per capita data from United Nations. 1976. World Energy Supplies. Series J, 1950-74. New York; United Nations. 1979. World Energy Supplies. Series J, 1973-78. New York. Puerto Rico GDP data for 1955 and 1960 from J. Freyre. 1979. El Modelo Economico de Puerto Rico. San Juan: Inter-American University Press. p. 253. Puerto Rico GDP data for 1950 and 1965-77 from J. Freyre. 1979. Long Term Projections of the Puerto Rican Economy. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Table 3. United States GNP data from Council of Economic Advisers. January 1979. Economic Report of the President. Washington, D.C.: Executive Office of the President. Table B-2 (converted to 1954 dollars).

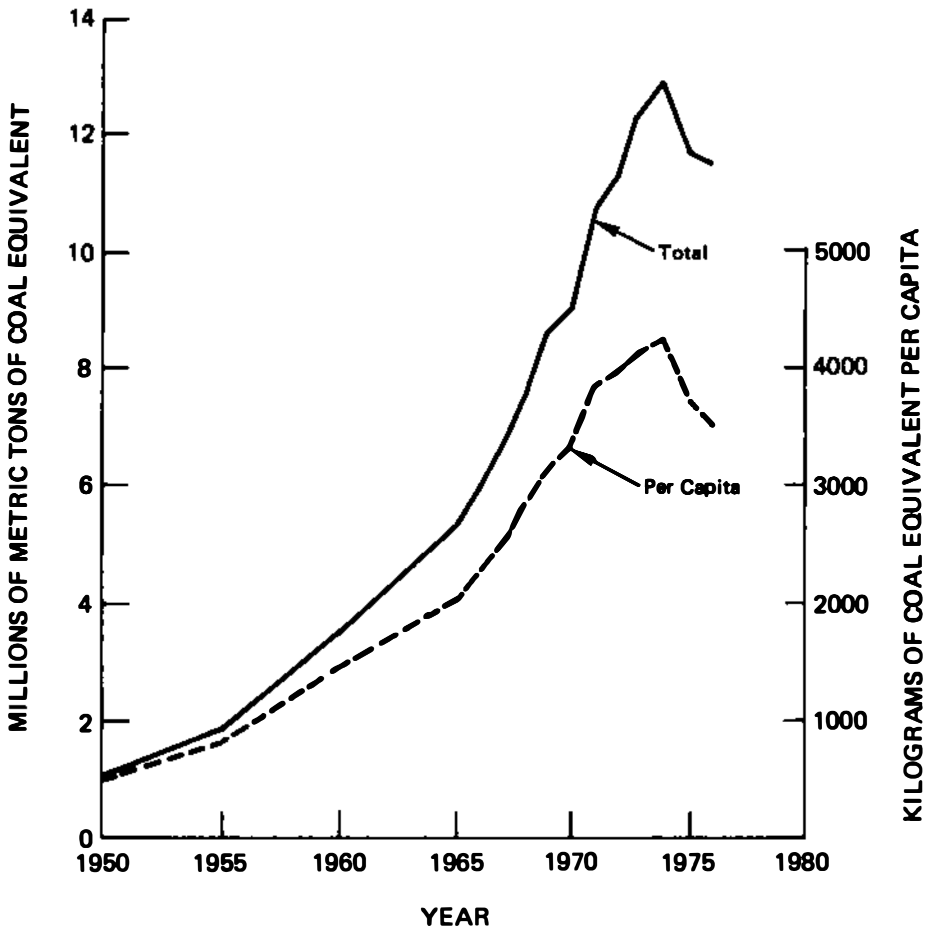


Figure 3 Total and per capita energy consumption in Puerto Rico, 1950-1976, in millions of metric tons coal equivalent and kilograms coal equivalent per capita

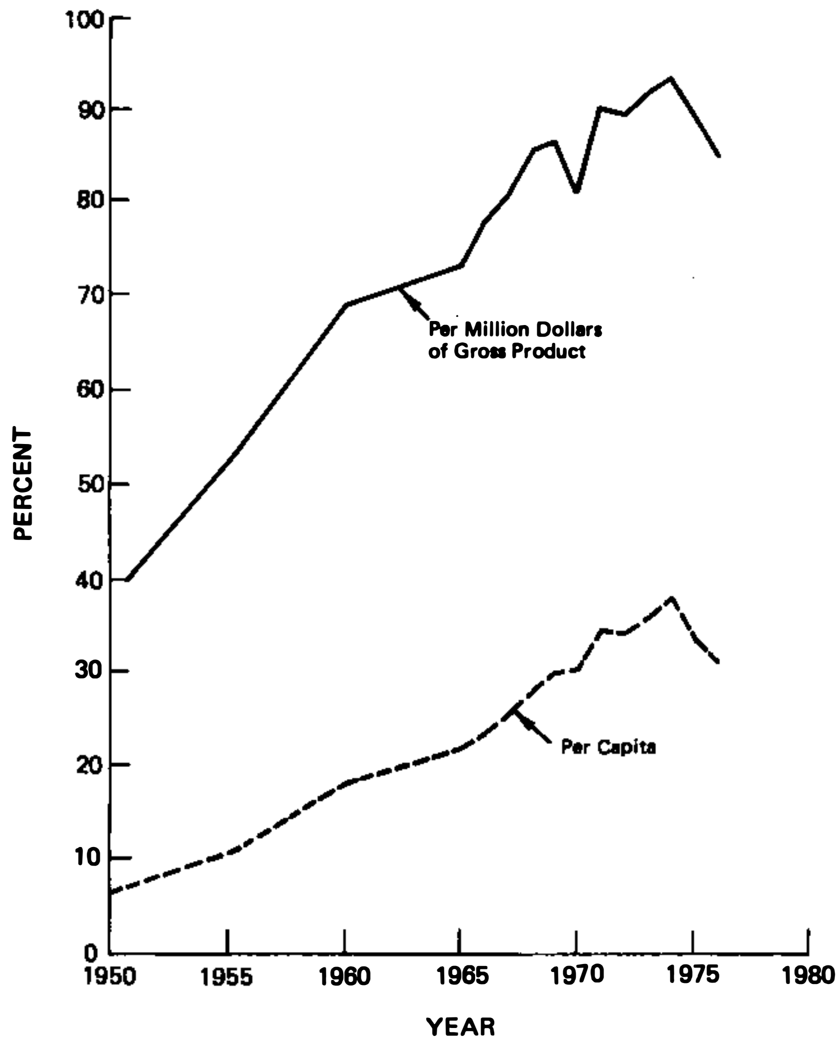


Figure 4 Puerto Rican energy consumption, 1950–1976, per million dollars of gross product and per capita, as percentage of United States values

Table 4 Puerto Rican trade in petroleum and petroleum products

Year	Imports			Exports			Net imports			Gross product (millions of dollars)	Value of net imports (percentage of GDP)
	Volume (millions of barrels)	Value (millions of dollars)	Average price (dollars per barrel)	Volume (millions of barrels)	Value (millions of dollars)	Average price (dollars per barrel)	Volume (millions of barrels)	Value (millions of dollars)	Average price (dollars per barrel)		
1968	67.1	160.2	2.39	23.6	99.2	4.20	43.5	61.0	1.40	3,680	1.7
1973	129.0	338.6	2.62	38.3	209.6	5.47	90.7	129.0	1.42	6,270	2.1
1974	126.6	931.3	7.36	49.5	447.2	9.03	77.1	484.1	6.28	6,798	7.1
1975	112.3	1,271.0	11.32	30.6	432.8	14.14	81.7	838.2	10.26	7,136	11.7
1976	114.4	1,318.6	11.53	24.3	339.8	13.98	90.1	1,041.7	11.56	7,508	13.9
1977	125.9	1,671.5	13.28	33.0	493.1	14.94	92.9	1,178.4	12.68	8,094	14.6

Source: Compiled from material supplied by Andres J. Velasquez, Office of Economic Research, Economic Development Administration, Commonwealth of Puerto Rico; based on data from U. S. Department of Commerce.

As the history outlined in this chapter indicates, the oil price rise and recession of 1974-1975 sharply changed Puerto Rico's energy consumption. Both total energy use and electricity use declined for the first time, with modest increases in electricity use in 1976 and overall energy use in 1977. As in the mainland United States and in other industrial countries, high prices induced some conservation and improved efficiency in energy use; this is reflected in the declining ratios of energy consumption to gross domestic product.

In the coming decades, Puerto Rico must find solutions to a problem that faces it and the entire world. That problem is how to survive in a world where the prices of petroleum and petroleum products continues to rise and their supply becomes increasingly less assured. This report addresses this central problem, and Puerto Rico's unique situation, in hopes of aiding the people of Puerto Rico in this task.

NOTES

1. Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. p. 31.

2. National Research Council. 1967. Science and Technology in Support of the Puerto Rican Economy. Committee on the Scientific and Technologic Base of Puerto Rico's Economy, Division of Engineering. Washington, D.C.: National Academy of Sciences.

3. Merrill Lynch White Weld Capital Markets Group. September 1978. PRWRA $32,000,000 Electric Revenue Bonds (Series 1978), $93,000,000 Power Revenue Bonds (Series E). Official Memorandum.

4. The Pace Company Consultants and Engineers, Inc. January 1979. Refining and Petrochemicals in Puerto Rico. Report prepared for the Puerto Rican Refining/Petrochemical Group. Houston, Texas.

5. Commonwealth Reorganization Co., Inc. December 1978. First Phase Report to Commonwealth Oil Refining Company, Inc., the United States District Court for the Western District of Texas, and the Creditors' Committee. San Antonio, Tex.

6. U.S. Army Corps of Engineers. 1977. Ponce Regional Water Resources Management Study. Appendix D: Technical Appendix, part VI, (Hydroelectric Power Potential). Report prepared for the Jacksonville District and the Government of Puerto Rico. p. VI.-37

7. Arthur D. Little, Inc. October 1977. Competitive Cost Position of the Puerto Rican Petrochemical Industry in 1977. Report to the Puerto Rico Petrochemical Group. Cambridge, Mass.

3 ENERGY DEMAND PROJECTIONS

This chapter presents two alternative projections of Puerto Rico's aggregate energy requirements over the next two decades, as a basis for evaluating different energy technologies and conservation strategies. Because the projections are intended as aids in evaluating new policies and technologies, they incorporate only those policies and programs currently in force or clearly forseeable.

It should be emphasized that this is a most difficult period in which to make energy projections. It will be some time yet before we understand completely how the demand for energy is responding to the unprecedented price increases of the last few years. It is also very hard to predict the future price of petroleum, and the prices and availabilities of alternative energy supplies and technologies. We would emphasize again the conditional and heuristic nature of these projections. They should be considered as one element in a complex process of decision making in an uncertain world. As further data become available and as Puerto Rican energy policies continue to develop, the projections should be altered and refined to provide a continually improving basis for decisions.

To be useful in evaluating policies and technological developments that may affect particular energy uses or sectors of the economy, energy demand must be projected in some detail by end use. Unfortunately, the available information on energy use in Puerto Rico is insufficiently detailed for this purpose, and the projections in this chapter were made largely by inference from combinations of data, or by disaggregating available data using the most plausible information available. The resulting aggregate energy demand projections may be reasonably reliable, but the details are considerably less certain of accuracy. The disaggregated demand projections should be considered as means for analyzing technology substitutions and policies rather than as predictions in a strict sense. The sensitivity of the results to variations in particular assumptions should be kept in mind.

This committee made two demand projections, case A and case B, based on explicit assumptions about population growth, levels of economic activity, and efficiencies of energy conversion. The projections have energy consumption values for the years 1985 and 2000, and are based on 1977 as a starting point (with 1978 data used where available.) In constructing the two projections we have grouped those assumptions that would lead to higher energy demand in Case A and those leading to lower demand in Case B.

The degree of detail in each sector of energy demand selected for analysis in part reflects the detail of the available data. In the residential sector, for example, uses are disaggregated among cooking, water heating, air conditioning, lighting, and large appliances (refrigerators and televisions). The commercial sector has not been disaggregated and is treated a subsector of the industrial sector, although it would be worthwhile in the future to separate trade and commercial energy demands linked with freight transportation. The industrial sector is disaggregated among four groups--cement, pharmaceuticals, refining and petrochemicals, and "all other." The first three of these are extremely important in Puerto Rico, having accounted for nearly half the electricity consumed in industry in 1978. The "all other" category includes the important food processing, textile, and apparel industries and agriculture, which are analyzed as a group because there is little information about them. Lastly, the transportation sector is broken down among private automobiles, public transportation, freight, and aviation.

Electricity demand is not treated as a separate sector in our analysis. Instead, electricity requirements in all sectors are totaled and the fuels required to generate that electricity are added to those consumed directly.

The projected energy requirements are derived from assumptions about population growth and the character of economic growth, but energy policies can in turn affect the Island's entire economic future. Energy prices, conservation initiatives, and the energy technologies that are chosen will help determine levels and trends in overall production, investments, trade, employment, and so on. In evaluating energy policies and programs, one must give careful consideration to their economic and social effects.

CURRENT ENERGY SUPPLY

Puerto Rico is nearly totally dependent on petroleum for its energy needs, and all of its petroleum is imported. This situation is typical of several island economies that lack energy resources. Puerto Rico's energy use, however, is unusual in that nearly 50 million of the 120 million barrels of crude and refined products that are imported are in turn exported, largely to the U.S. mainland as middle distillates, gasoline, and residual oil. About another 16 million are consumed in the refining process and by the petrochemical industry (the products of which in turn are largely exported.) Besides consumption as feedstocks and fuel in the petrochemical and refining complexes, the largest single uses of petroleum in Puerto Rico are electricity generation with residual oil and transportation fueled by gasoline.

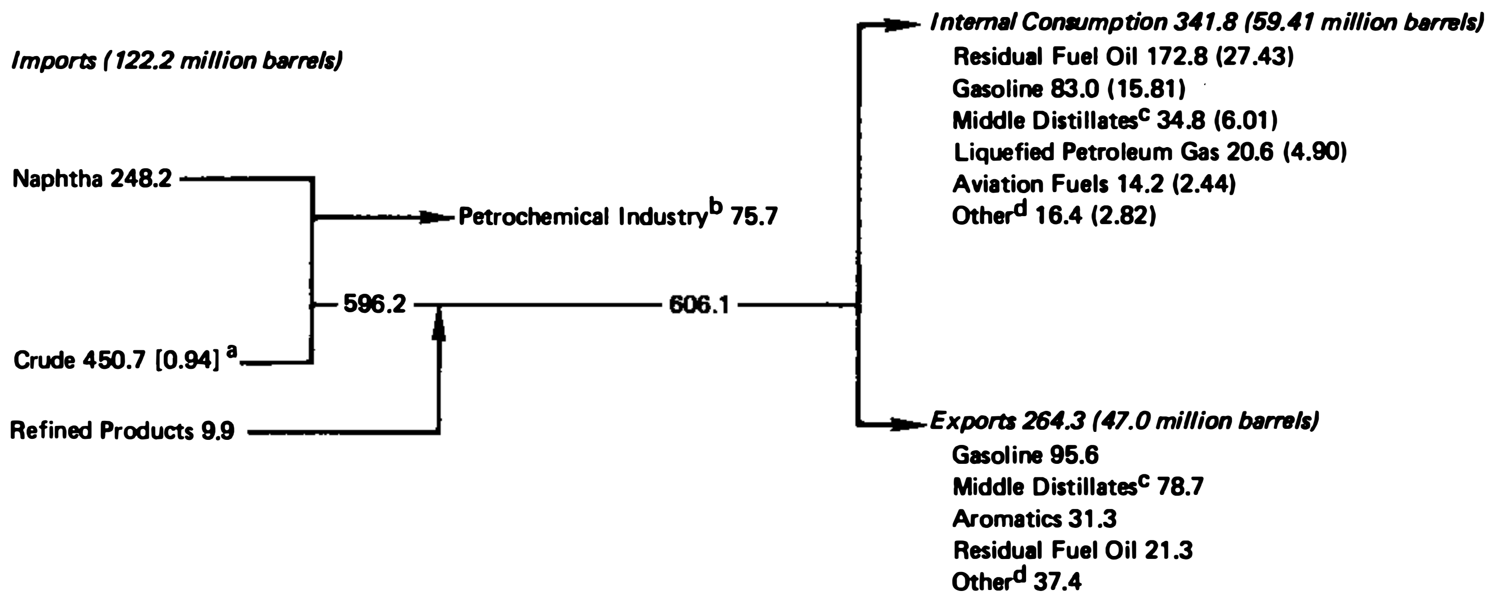
Petroleum

The statistics on petroleum consumption in Puerto Rico are confused, largely by the distortion created by large petrochemical feedstock imports. Naphtha (a petroleum-based feedstock that is converted to a range of chemicals and other nonenergy products) does not appear as output in an energy balance. The statistics published by the Office of Petroleum Fuels Affairs[1] resolve this by excluding naphtha imports to petrochemical plants from totals. The Office of Energy[2], however, publishes statistics in which all naphtha imports are included, and this report follows that convention.

The destinations of imports are three: local consumption (for electricity generation, manufacturing, transportation, and cooking), export (gasoline, distillates, etc.) and use as fuel and feedstock in the petrochemical industry and refineries. Figure 5 is a diagram of petroleum supply and disposition on the island for 1977. A total of 698.9 trillion Btu (TBtu), or 120 million barrels of crude oil and naphtha, and 9.9 TBtu (1.7 million barrels) of petroleum products were imported that year. A total of 264.3 TBtu (about 47 million barrels) were exported, with the balance consumed on the Island. Of this balance, 341.8 TBtu (59 million barrels) were distributed to customers by the petroleum companies; the consumption by refineries, as indicated in Figure 5, is a loss of 6 percent, and the total feedstock and fuel input to the petrochemical industry is shown as an estimated 75.7 TBtu.

Total imports of crude oil and petroleum products have remained relatively stable since 1974, except for significantly lower naphtha consumption in 1975 and 1976. The growth in exports of petroleum products from Puerto Rican refineries has been slight since the 1973-74 oil crisis. Tables 5 and 6 present the import and export figures through 1977.

Internal consumption in 1977 was 59.4 million barrels; 21.5



[a] The factor [0.94] represents the conversion efficiency of refineries.
[b] Some flows from refinery to petrochemical industry to export are included in direct exports.
[c] Diesel fuel, kerosene, and heating oil.
[d] Lubricating oil, asphalt, etc.

Figure 5 Petroleum supply and disposition in 1977, in trillions of Btu (Parenthesized numbers represent millions of barrels.) (Oficina de Energia. November 1978. Estadisticas Sobre el Petroleo y sus Productos Ano Natural 1977. San Juan: Oficina del Governador de Puerto Rico.)

Table 5 Petroleum imports, 1974-1977, in millions of barrels

Product	Year			
	1974	1975	1976	1977
Crude	74.2	70.3	83.1	77.7
Naphtha	40.2	31.9	35.7	42.8
Petroleum products	8.7	4.2	2.2	1.9
Total	123.1	106.4	121.0	122.4

Source: Oficina de Energia. November 1978. Estadisticas Sobre el Petroleo y sus Productos Ano Natural 1977. San Juan: Oficina del Governador de Puerto Rico.

Table 6 Petroleum exports, 1974-1977, in millions of barrels

Product	Year			
	1974	1975	1976	1977
Gasoline	16.7	16.6	14.0	18.2
Middle distillates	11.7	10.8	12.4	13.6
Residual fuel oil	3.2	3.6	6.8	3.4
Aromatics	6.2	4.4	6.4	5.4
Other	4.3	2.9	3.1	6.4
Total	42.1	38.3	42.7	47.0

Source: Oficina de Energia. November 1978. Estadisticas Sobre el Petroleo y sus Productos Ano Natural 1977. San Juan: Oficina del Governador de Puerto Rico.

million barrels of this were consumed by the Puerto Rico Water Resources Authority (now Puerto Rico Electric Power Authority) in generating electricity, 19.2 million barrels by the transportation sector; and 14.4 million barrels by industrial and commercial activities (excluding refineries and petrochemicals). The residential sector consumed less than 1 million barrels directly. The remainder consisted of nonenergy petroleum products such as asphalt and lubricants.

Table 7 shows selected sales data obtained from the Office of Energy[2], which has published internal consumption data only for the year 1977; for previous years the data are reported as "sales by refineries" or "sales by wholesalers". The latter could serve as a measure of internal use, except that large customers, such as the Puerto Rico Electric Power Authority (PREPA), are omitted.

It is important to remember that the petroleum consumption figures in Table 7 exclude consumption by the refining and petrochemical industries. Internal use by refineries can be estimated by applying a conversion efficiency factor of 0.94 to the total amount of crude oil imported to the Island. That is, 6 percent, or 350,000 Btu of energy are lost from the average barrel of crude oil (at about 5.8 million Btu per barrel) refined.

About 40 percent of the naphtha imported into Puerto Rico is used by the petrochemical industry, which produces olefins, vinyl chloride, caustic soda, and other chemicals. The other 60 percent is used in integrated refining and petrochemical plants, which produce petroleum products, aromatics, and feedstocks for the other chemical plants. Naphtha is in addition produced domestically in refining crude oil.

Energy use by the petrochemical sector can be measured only by complex energy balances of the industry, and no such detailed analysis exists. Chapter 4, on the oil refining and petrochemical industries, discusses the special situation of this important sector of the Island's economy. In view of the recent plant shutdowns and the uncertain future of the industry, past fuel use by this sector would shed little light on future consumption.

Electricity Generation

Except for a few industries that generate small amounts of their own electricity the Puerto Rico Electric Power Authority is the only source of electricity in Puerto Rico. (Generating capacity in industry totals 77.9 megawatts with four installations in the pharmaceutical industry and one each in the petrochemical, sugar refining, and textile industries;[3] the output of these units is not reported.) PREPA's total generation in 1977 was 13,291 million kWh, and sales were 11,698 million kWh, with the difference lost in transmission and distribution.[3] Virtually all this electricity was generated from petroleum, in four oil-fired steam plants and nine diesel and gas turbine groups. Hydroelectric plants produce only about 1 percent of the Island's electricity,

Table 7 Domestic sales, 1972-1977, in millions of barrels

Product	Year					
	1972	1973	1974	1975	1976	1977
Gasoline, sales by wholesalers	12.7	13.8	13.6	14.0	15.1	15.8
Residual, sales by refineries	22.2	23.6	26.9	23.8	22.7	25.8[a]
Middle distillates, sales by refineries	4.9	8.0	4.4	5.0	6.6	6.3[b]
Aviation fuels, sales by whole-salers	(c)	(c)	1.9	1.9	1.8	2.4
Liquefied petroleum gas, sales by wholesalers	1.7	1.8	1.4	1.3	1.4	1.3[d]
Asphalts and lubricants	(c)	(c)	(c)	(c)	(c)	2.8

[a]Internal consumption is reported at 27.4 million barrels of residual oil.

[b]Internal consumption is reported at 6.0 million barrels of middle distillates.

[c]Not available

[d]Internal consumption is reported at 4.9 million barrels of liquefied petroleum gas.

Source: Oficina de Energia. November 1978. Estadisticas Sobre el Petroleo y sus Productos Ano Natural 1977. San Juan: Oficina del Governador de Puerto Rico.

and they are the only capacity in Puerto Rico not fired by oil. Puerto Rico's installed electrical capacity is 4,207 megawatts (Table 8), consisting mainly of 18 steam generating units with capacities ranging from 44 to 460 megawatts. Peak demand is about 2000 megawatts. At any given time many of the units are closed for maintenance and repairs, and some units have load restrictions.

The generating system consumed in 1977 a total of 126.0 TBtu of residual oil (20 million barrels) and 8.7 TBtu of diesel fuel (1.5 million barrels). The conversion efficiency of their system is 33.7 percent; internal use and transmission and distribution losses amount to 15.5 percent.[4] Nearly one third of total electricity sales are consumed by the residential sector. The rest is consumed by industrial and commercial establishments, among whom the largest consumers are refineries and petrochemical plants, which consume half of the industrial electricity total. Figure 6 shows the energy balance for the electricity subsystem, and Table 9 presents the breakdown of sales for the period 1960 to 1979.

ECONOMIC AND DEMOGRAPHIC PROJECTIONS

The future energy needs of Puerto Rico will depend on a number of economic factors; such as the pattern and rate of economic growth, population growth rates, the prices and availabilities of fuels, new technologies, and government policies in a variety of areas. This section summarizes the economic and demographic determinants of future energy demand, as described by Jorge F. Freyre in his report to the Committee.[5] The specific technical assumptions underlying the Committee's energy projections are presented in this chapter under the heading "Energy Demand Projections."

Long-Range Economic Projections

The economic projections with which this committee dealt are based on analyses of past trends and on judgments and assumptions about institutional and economic developments. For presentation purposes, the planning period has been subdivided into three subperiods: 1978-1985, 1985-1990, and 1990-2000. Regarding political status, it has been assumed that even were statehood achieved before the year 2000, many special conditions, such as the partial tax exemption for attracting manufacturing investment, would be unchanged.

The projections recognize that Puerto Rico is basically a region within the U.S. economy. For the purposes of this committee's energy demand projections, long-run forecasts for the U.S. economy were based on results of the Wharton Annual Model, adjusted to account for decontrol of domestic oil prices and uncertainties in the future energy situation. The resulting projected growth rates in U.S. GNP were 2.6 percent in

Table 8 Puerto Rico Electric Power Authority generating capacity, 1979

Generating stations	Total name plate rating (78 units)[a]	Dependable generating capacity, in megawatts					
		Total (78 units)	Steam-electric (18 units)	Gas turbine (32 units)	Jet turbine (1 unit)	Hydro (19 units)	Other (8 units)[b]
Aguirre	1,540	1,530	900[c]	630[d]	-	-	-
South Coast	1,113	1,128	1,090	38	-	-	-
Palo Seco	717	716	602	114	-	-	-
San Juan	488	488	488	-	-	-	-
Mayaguez	80	76	-	76	-	-	-
Other	282	269	-	152	16	98	3
Total	4,220	4,207	3,080	1,010	16	98	3

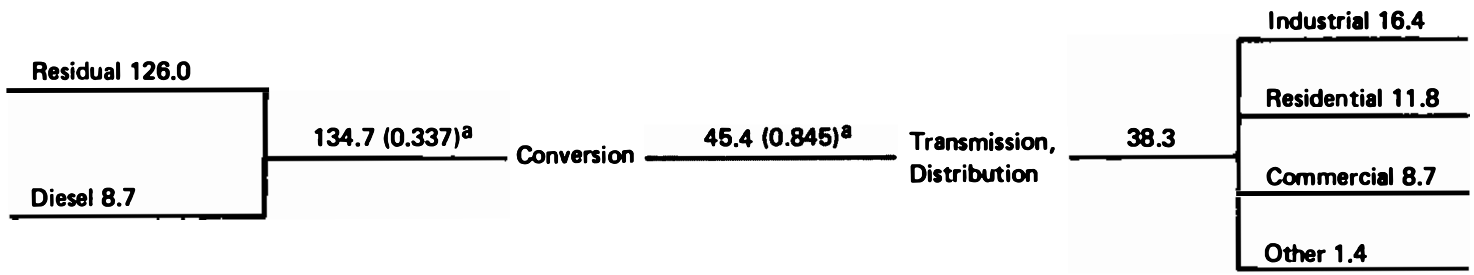
[a]Excludes two gas turbine units (aggregate name plate capacity 40 megawatts), which the Authority plans to retire, and ten jet turbine units (aggregate name plate capacity 150 megawatts), which the Authority plans to sell or retire.

[b]Includes four diesel units on the island of Culebra and three on the island of Vieques (aggregate dependable generating capacity 2.7 megawatts) held on standby reserve and one wind turbine generator on the island of Culebra with a capacity of 200 kilowatts.

[c]Consists of the two largest units in service, Aguirre Units 1 and 2, each with a dependable generating capacity of 450 megawatts.

[d]Includes two combined cycle units, each made up of four 50-megawatt gas turbines and one heat recovery unit powering a 96-megawatt steam turbine.

Source: Merrill Lynch White Weld Capital Markets Group. September 1978. Puerto Rico Water Resources Authority $32,000,000 Electric Revenue Bonds (Series 1978), $93,000,000 Power Revenue Bonds (Series E). Official Memorandum.



[a]Factors in parentheses represent the efficiencies of conversion and of transmission and distribution.

Figure 6 Electricity supply and consumption, 1977, in trillions of Btu; 3,413 Btu = 1 kWh. (Data from Puerto Rico Water Resources Authority. October 1976 through December 1978. General Monthly Reports. Production Division. San Juan.)

Table 9 Consumption of electricity by major classes of customers: selected years 1960-1979

Fiscal year	Residential		Industrial[a]		Commercial[b]		Public lighting and others		Total (millions of kWh)
	Millions of kWh	Percentage of total	Millions of kWh	Percentage of total	Millions of kWh	Percentage of total	Millions of kWh	Percentage of total	
1960	587	35.2	569	34.1	402	24.1	109	6.5	1,667
1965	1,193	37.4	923	29.0	824	25.9	246	7.7	3,186
1970	2,415	37.2	1,988	30.6	1,589	24.5	503	7.7	6,495
1973	3,277	32.5	4,180	41.5	2,162	21.4	465	4.6	10,084
1974	3,330	32.1	4,406	42.5	2,230	21.5	411	4.0	10,377
1975	3,196	31.3	4,339	42.6	2,283	22.4	380	3.7	10,197
1976	3,277	31.0	4,558	43.1	2,352	22.2	388	3.7	10,575
1977	3,462	30.8	4,807	42.8	2,553	22.7	408	3.6	11,230
1978	3,630	31.4	4,841	41.9	2,654	22.9	442	3.8	11,567
1979	3,661	31.6	4,709	40.7	2,784	24.1	418	3.6	11,572

[a]Includes consumption by agricultural firms. The consumption of electricity by the agricultural sector was segregated for the first time in fiscal year 1978, and amounted to only 33.9 million kWh.

[b]Includes electricity consumed by government agencies and instrumentalities, except for public lighting.

Source: Merrill Lynch White Weld Capital Markets Group. September 1978. Puerto Rico Water Resources Authority $32,000,000 Electric Revenue Bonds (Series 1978), $93,000,000 Power Revenue Bonds (Series E). Official Memorandum.

1979-85, 2.8 percent in 1985-90, and 2.9 percent in 1990-2000. Corresponding growth rates for Puerto Rico were derived by analyzing key institutional and economic factors to give projections of overall economic expansion and real output in the major sectors of the economy. The key trends and prospects in the major sectors of the Puerto Rican economy are described below.

Economic Trends and Prospects in Puerto Rico

It is assumed in the projections that despite full adherence by most manufacturers to the federal minimum hourly wage in Puerto Rico by 1981, a substantial differential in average wage rates should prevail between the United States and Puerto Rico, except in such labor-intensive industries as apparel and textiles. Nonetheless, continued declines in employment and real output of labor-intensive industries are expected throughout the projected period. This applies to the tobacco, textile, apparel, furniture, and leather industries.

Capital-intensive industries as a whole should experience a significant expansion in both employment and real production during the planning period, although growth of output will far exceed that of employment. The most dynamic industry is expected to be pharmaceuticals, followed by nonelectrical machinery. The outlook for stone, clay, glass, and concrete products is not very promising in view of the dim outlook for the construction industry. The prospects for the refining and petrochemicals sector are discussed in Chapter 3 in detail, reflecting this sector's importance in Puerto Rico's economy (and energy use) and the considerable uncertainty about its future.

The future behaviors of trade, services, and other private sectors, excluding tourism, are closely related to the overall performance of the Puerto Rican economy. An increase in the relative importance of the service sector, especially in terms of employment, is predicted; other sectors are assumed to grow at the same rates as total GDP.

Finally, the long range projections of the government sector assume no major overhaul of the present tax system, and growth in transfer payments from the federal government at a lower rate than those experienced in recent years.

As noted in Chapter 2, Puerto Rico's gross domestic product (GDP) over the past few decades has grown more rapidly than the U.S. GNP. Between 1970 and 1978, the Puerto Rican GDP averaged 3.6 percent, as compared to 2.9 percent in the United States as a whole. On the basis of the above trends and prospects, the assumed growth rates for the Puerto Rican GDP are 4.0 percent for 1978-85, 3.8 percent for 1985-90, and 3.7 percent for 1990-2000. Table 10 displays the application of the judgments summarized above to the sectoral composition of the Puerto Rican GDP to the year 2000, as projected in Case A (the higher growth projection). Table 11 lists the corresponding growth rates assumed for the GDP and the main sectors that compose it.

Table 10 Gross domestic product by major sectors: fiscal year 1978 and projections for 1985-2000 (Case A)

Sector	Amount (millions of 1978 dollars)				Percentage of total			
	1978	1985	1990	2000	1978	1985	1990	2000
Agriculture	303	365	407	505	2.8	2.5	2.3	2.0
Manufacturing	3,785	5,370	6,673	10,092	34.4	37.0	38.2	40.2
Construction	339	381	425	528	3.1	2.6	2.4	2.1
Transportation and other public utilities	969	1,261	1,520	2,160	8.8	8.7	8.7	8.6
Trade	1,810	2,319	2,742	3,768	16.4	16.0	15.7	15.0
Finance, insurance, and real estate	1,110	1,361	1,583	2,169	10.1	9.4	9.1	8.6
Services	1,141	1,623	2,043	3,190	10.4	11.2	11.7	12.7
Government	1,558	1,814	2,073	2,705	14.1	12.5	11.9	10.8
Total	11,014	14,494	17,465	25,117	100.0	100.0	100.0	100.0

Source: Adapted from Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

Table 11 Projections of annual growth rate of gross domestic product, in percent (Case A)

Sector	Years		
	1978-1985	1985-1990	1990-2000
Agriculture	2.7	2.2	2.2
Manufacturing	5.1	4.4	4.2
Contract, construction, and mining	1.7	2.2	2.2
Transportation and other public utilities	3.8	3.8	3.6
Trade	3.6	3.4	3.2
Finance, insurance and real estate	3.0	3.1	3.2
Services	5.2	4.7	4.6
Government	2.2	2.7	2.7
Total	4.0	3.8	3.7

Source: Adapted from Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

An alternative view, Case B, embodies assumptions of a lower demand for energy and lower rates of economic expansion. It implies a more pessimistic outlook about the future real growth rate of the U.S. economy: 1.8 percent for 1978-85, 2.0 percent for 1985-90, and 2.1 percent for 1990-2000. The more pessimistic view on prospects for Puerto Rico centers on the manufacturing sector, reflecting increased wages and higher energy and transportation costs. Decreases in growth from Case A are assumed also for agriculture and construction. Moreover, lower rates of economic growth should cause an increase in emigration, thus dampening population growth. As a result, the Puerto Rican GDP is estimated to grow at 2.8 percent in Case B for 1978-85, down from 4.0 percent in Case A, and 2.6 percent and 2.5 percent for 1985-1990 and 1990-2000 respectively, down from 3.8 percent and 3.7 percent for the same periods in Case A. Tables 12 and 13 present the projections of gross domestic product growth and its composition by major sectors for Case B.

Population and Households

The population projections used in the analysis were those prepared by Freyre,[6] which differ from those of the Economic Development Administration's Planning Board in their estimates of the immigration-emigration balance over the next 20 years. Based on the assumption that the growth rate in real production in Puerto Rico will not significantly exceed that of the United States, and that the Island will continue to face a difficult employment situation, it is unlikely that a persistent net immigration will flow to Puerto Rico, as projected by the Planning Board.

The factors determining migration movements between Puerto Rico and the mainland are poorly known, and even official data for certain years of the 1970's are not considered highly reliable. The population growth assumptions presented here are therefore based mainly on natural population increases. For Case A an average annual net emigration of 5,000 persons was assumed for the period 1978-90, with immigration and emigration in balance for the period 1990-2000. For Case B, an annual net emigration of 15,000 was assumed through the year 2000. The analysis shows a total population of 4,412,600 persons in the year 2000 for Case A and 4,071,300 persons for Case B.

Many residential uses of energy are more closely related to the number of households than to the total population. Unfortunately, statistics on the number of households in Puerto Rico are sketchy. The committee's projections use a figure of 738,000 families. An upper limit on households is given by occupied housing units (829,700 units) or by the number of residential electricity customers (781,000 customers). The analysis requires that second homes be subtracted from these totals.

The ratio between population and number of families, or the average number of persons per household, tends to decrease as average income increases, if recent trends in Western Europe and the U.S. mainland can serve as examples. The 1977 figure of 4.5 persons per household in Puerto Rico is assumed to decline by 1 percent per year in Case A to 3.6 persons in 2000, and at a slightly lower rate in Case B to 3.65 persons per household in that year. Applying the corresponding population figures, one obtains 1,226,000 households in the year 2000 in Case A and 1,115,000 in Case B. (See Table 14.) The decrease in

Table 12 Gross domestic product by major sectors: fiscal year 1978 and projections for 1985-2000 (Case B)

Sector	Amount (millions of 1978 dollars)				Percentage of total			
	1978	1985	1990	2000	1978	1985	1990	2000
Agriculture	303	334	353	394	2.8	2.5	2.3	2.0
Manufacturing	3,785	4,848	5,702	7,663	34.4	36.3	37.6	39.5
Construction	339	361	381	429	3.1	2.7	2.5	2.2
Transportation and other public utilities	969	1,176	1,337	1,695	8.8	8.8	8.8	8.7
Trade	1,810	2,137	2,383	2,905	16.4	16.2	15.7	15.0
Finance, insurance, and real estate	1,110	1,266	1,391	1,679	10.1	9.5	9.2	8.7
Services	1,141	1,522	1,808	2,501	10.4	11.4	11.9	12.9
Government	1,558	1,694	1,825	2,118	14.1	12.7	12.0	10.9
Total	11,014	13,338	15,180	19,384	100.0	100.0	100.0	100.0

Source: Adapted from Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

Table 13 Projections of annual growth rate of gross domestic product, in percent (Case B)

Sector	Years		
	1978-1985	1985-1990	1990-2000
Agriculture	1.4	1.1	1.1
Manufacturing	3.6	3.3	3.0
Construction	0.9	1.1	1.2
Transportation and other public utilities	2.8	2.6	2.4
Trade	2.5	2.2	2.0
Finance, insurance, and real estate	1.9	1.9	1.9
Services	4.2	3.5	3.3
Government	0.9	1.5	1.5
Total	2.8	2.6	2.5

Source: Adapted from Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

persons per household is somewhat speculative and uses as a basis trends on the United States mainland (less than 3.0 persons at present.) The sensitivity of the conclusions of the study to these assumptions should eventually be considered, particularly for the case of demand for electricity, one-third of which is consumed in households.

Table 14 Household projections

Year	Population (thousands)		Persons per family		Number of households[a] (thousands)	
	Case A	Case B	Case A	Case B	Case A	Case B
1976	3,214					
1977	3,319		4.5		738[b]	
1978	3,358					
1985	3,730	3,623	4.2[c]	4.2	888	863
1990	4,005	3,837				
1995	4,246	3,991				
2000	4,413	4,071	3.6[c]	3.65	1,226	1,115

[a]Calculated from population and persons per family estimates

[b]Number of families, extrapolated from data contained in Donovan, Hamester and Rattien, Inc. April 1979. Energy Data for Puerto Rico. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

[c]Estimates

Source: Adapted from Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

ENERGY DEMAND PROJECTIONS

Residential Sector

The energy demand projections for the residential sector relate demand to the basic household needs of cooking, lighting, domestic water heating, and the use of appliances. The driving force in the increase in residential energy use is the growth in the number of households. An attempt is made to describe the typical energy use for each household purpose or device; this permits evaluation of the effects of increases in efficiency, changes in the rates of ues, or the substitution of new sources of energy, such as solar water heaters for electric water heaters. This detailed approach can be used in conjunction with the macro-economic approach favored by other forecasters.

Direct consumption of petroleum products by residences amounts to no more than 2 percent of total petroleum use in Puerto Rico. About 40 percent of families use bottled gas (LPG) for cooking[7], and an estimated 45 percent use electricity.[8] Presumably the remaining 15 percent use kerosene, though this assumption is uncertain. Similarly, there is no quantitative information on the use of firewood or charcoal for particular uses (such as bread making) in rural communities.[9] The number of residences using bottled gas for water heating appears to be negligible.

Information on electricity use by households is more readily available. Nearly one-third of all electricity used in Puerto Rico is consumed in residences, although this share has decreased with growing industrialization. Estimates of average monthly consumption per residence were obtained from the Electric Power Authority for cooking, water heating, refrigeration, air conditioning, and televisions. Data on saturation (the proportion of homes owning a particular device) are not collected systematically, but have been estimated from the results of sample surveys and the outdated census. Tables 15 through 19 present this information and include some details of the assumptions used in extrapolating to the year 2000. The unit energy demand multiplied by the number of households with the device (i.e., total units multiplied by the saturation) yields total energy use for that subsector. In cases for which conversion efficiency is less than 1.0, total energy use is obtained by dividing by the efficiency.

The residential sector demand projections are based on the number of households assumed for Case A and Case B in the year 1985 and 2000 respectively. (See Table 14.) Unit energy demands[10] are kept constant except for selected large appliances such as air conditioners, for which federally mandated efficiency improvements will reduce unit consumption, and for miscellaneous uses (i.e., small appliances). The demand per household in this last category (which includes lighting)

Table 15 Energy use in cooking[a]

Year	Electricity		Liquefied petroleum gas		Kerosene		Number of households (thousands)	Unit energy (millions of Btu per year)
	Fraction of cooking demand served	Demand (trillions of Btu)	Fraction of cooking demand served	Demand (trillions of Btu)	Fraction of cooking demand served	Demand (trillions of Btu)		
1977	0.45[b]	1.37	0.40[b]	2.02	0.15	1.44	738	4.1
1985								
Case A	0.45	1.64	0.45	2.73	0.10	0.91	888	4.1
Case B	0.45	1.59	0.45	2.65	0.10	0.88	863	4.1
2000								
Case A	0.45	2.26	0.55	4.61	0.0	0.0	1,226	4.1
Case B	0.45	2.06	0.55	4.19	0.0	0.0	1,115	4.1

[a]Conversion efficiencies: electricity 1.0; liquefied petroleum gas 0.60; kerosene 0.40

[b]See notes 7 and 8.

Table 16 Energy use in water heating

Year	Demand		Saturation	Number of households (thousands)	Unit energy (millions of Btu per year)[a]
	Electricity (trillions of Btu)	Liquefied petroleum gas (trillions of Btu)			
1977	3.93	0+	0.65[a]	738	8.2
1985					
Case A	5.09	--	0.70	888	8.2
Case B	4.77	--	0.70	863	7.9
2000					
Case A	8.04	--	0.80	1,226	8.2
Case B	6.19	--	0.75	1,115	7.9

[a]Saturation of 0.65 in 1977 is obtained from Puerto Rico Water Resources Authority data on number of customers having electric hot water heaters. Electricity use per water heater is also obtained from Puerto Rico Water Resources Authority. (The 1977 value of 8.2 million Btu per year corresponds to a consumption of 200 kWh per month.) The combination of these figures may overestimate somewhat the amount of electric water heating given the fact that about 45 percent of residential customers use less than 225 kWh per month. (Personal communication. October 26, 1979. Osvaldo Goyco, Puerto Rico Water Resources Authority, to John Berga, National Academy of Sciences.

Table 17 Energy use in air conditioning

Year	Electricity (trillions of Btu)	Saturation[a]	Number of households (thousands)	Unit energy (millions of Btu per year)
1977	1.23	0.12[b]	738	13.9
1985				
Case A	1.92	0.16	888	13.5
Case B	1.75	0.15	863	13.5
2000				
Case A	3.81	0.28	1,226	11.1
Case B	2.60	0.21	1,115	11.1

[a]This estimate implies the existence of about 88,000 air-conditioned homes on the Island. GKCO estimates this amount to be 75,000, based on the assumption that all Puerto Rico Electric Power Authority customers using more than 700 kWh per month have air conditioners (GKCO Consultants. October 1979. Energy Conservation Measures for Puerto Rico. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.)

[b]Saturation is increased at the rate of growth of personal income (Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.) Unit energy demand decreased in 2000 by 20 percent to account for increases in coefficient of performance.

Table 18 Energy use by television and refrigerator

Year	Electricity (trillions of Btu)	Saturation[a]	Number of households (thousands)	Unit energy (millions of Btu per year)[b]
1977	3.37	0.80	738	5.7
1985				
Case A	4.40	0.87	888	5.7
Case B	4.28	0.87	863	5.7
2000				
Case A	6.99	1.0	1,226	5.7
Case B	6.35	1.0	1,115	5.7

[a]Saturation in 1977 is taken at 0.80 to account for small refrigerators, black and white television sets, etc. Penetration of these appliances is given at 100 percent by 2000.

[b]The unit consumption of 5.7 million Btu per year is equivalent to 140 kWh per month, with the typical refrigerator consuming 90 kWh per month and the typical television consuming 50 kWh per month.

is allowed to increase at the assumed rates of increase in personal income for Cases A and B, to account for the purchase of additional appliances and increased use of existing ones, but is reduced by 1 percent per year to account for price-induced conservation.

A second determinant of final demand is the level of saturation. By the year 2000, the number of households with electric water heaters is allowed to grow from 65 to 80 percent of all households in Case A, and from 65 to 75 percent in Case B. (There is some doubt about whether all water heaters now installed are actually being used; see the note to Table 16.) Similarly, ownership of air conditioners is allowed to rise by 2000 to 28 and 21 percent of all households in Case A and B respectively, from a 1977 saturation of 12 percent.

Table 19 Energy use by lighting and miscellaneous appliances

Year	Electricity (trillions of Btu)	Number of households (thousands)	Unit energy (millions of Btu per year)[a]
1977	1.90[b]	738	2.57
1985			
Case A	2.83	888	3.18
Case B	2.51	863	2.91
2000			
Case A	5.65	1,226	4.61
Case B	3.94	1,115	3.53

[a]Unit energy demand grows at the growth rate of personal income to account for new appliances but is reduced by 1 percent per year to account for the effect of increased prices.

[b]Obtained as a difference from total electricity sales to residential sector.

These increases are in line with the basic personal income growth stipulated for Cases A and B.

Table 20 is a summary of the residential electricity projection. Residential demand grows from 3,460 million kWh in 1977 to 4,653 million kWh in 1985 for Case A (3.8 percent growth per annum), and 4,366 million kWh in 1985 for Case B, (3.0 percent growth). For the year 2000, residential electricity requirements total 7,838 million kWh in Case A and 6,194 million kWh in Case B; this growth between 1985 and 2000 corresponds to annual growth rates of 3.5 and 2.4 percent for Cases A and B respectively. The most recent Electric Power Authority projections for the residential sector go only as far as

Table 20 Summary, residential electricity demand, in trillions of Btu

End use	1977	1985		2000	
		Case A	Case B	Case A	Case B
Cooking	1.37	1.64	1.59	2.26	2.06
Water heating	3.93	5.09	4.77	8.04	6.19
Air conditioning	1.23	1.92	1.75	3.81	2.60
Television, refrigerator	3.37	4.40	4.28	6.99	6.35
Lighting and miscellaneous appliances	1.90	2.83	2.51	5.65	3.94
Total	11.80	15.88	14.90	26.75	21.14

1983, but by extrapolating at the 1982-1983 growth rate of 4.7 percent we obtain a 1985 sales figure of 4,764 million kWh, which is within 2 percent of this committee's Case A projection.

Transportation Sector

The transportation sector in Puerto Rico, which is dominated by the automobile, consumed nearly 13 million barrels of gasoline in 1977 (67.7 TBtu). In fact, were Puerto Rico a nation, it would rank sixth in the world in per capita car ownership, with one auto for each four persons. Data for 1975 show an average of 8,990 miles per vehicle in Puerto Rico, less than 5 percent under the United States average. The annual consumption of 692 gallons per passenger vehicle in Puerto Rico was slightly above the United States average in that year.[11]

The growth in automobile use is reflected in the 10 percent average annual growth in gasoline sales in the five years prior to 1973; the growth rate has averaged 3.5 percent per year since then. The share of premium gasoline in the total market has increased to nearly 80 percent from a pre-1973 level of 65 percent.

Table 21 Puerto Rican vehicle fleet, fiscal year 1977

Mode	Number of vehicles (thousands)
Personal vehicles	
Privately owned autos	660
Light trucks	93
Subtotal	753
Public vehicles	
Buses	2
Fore-hire autos and vans	13
Taxis	2
Subtotal	17
Freight vehicles	
Heavy trucks and tractors	25
Trailers	19
Subtotal	44
Cycles	7
Government vehicles	9
Total	830

Source: R. Shackson. August 1979. Assessment of Opportunities for Conservation in the Transportation Sector and Strategies for Implementation. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Arlington, Va.: Mellon Institute-Energy Productivity Center.

The increased use of the private automobile has been paralleled by a decrease in public transport ridership. Bus ridership in the last several years has declined more than 25 percent, and the decline has persisted despite the rise in gasoline prices. A more efficient and reliable public transportation system would be required to stem and reverse this decline. (See Chapter 6.) During 1975, one-fourth of the San Juan system's 390 buses were out of service daily due to mechanical problems or driver absenteeism. The average service life of a bus during this period was less than 10 years because of poor maintenance performance and lack of an established maintenance program. In addition, service in the system had deteriorated to average speeds of less than 10 miles per hour. All of these factors contributed to a growing preference for the private automobile. In addition, buses have been replaced for many trips by publicos (taxis with fixed routes and multiple riders).

Intercity public transportation appears to be dominated by publicos, with buses in a smaller role. Intercity transport by air is negligible in terms of fuel consumption. Consumption of jet fuel on the Island (14.2 TBtu in 1977) is overwhelmingly for flights with destinations outside Puerto Rico.

In fiscal 1977 the vehicle fleet of Puerto Rico included about 830,000 units, in the categories shown in Table 21. Private automobiles total about 660,000 units. Because roughly one-third of the automobiles imported into Puerto Rico each year are used cars (predominately of U.S. manufacture) the fleet is older than that of the mainland and would ordinarily be expected to have a higher percentage of large cars and therefore poorer fuel economy. A compensating factor, however, is the large representation of foreign vehicles (about one-third of the total fleet). The result is a weighted average fuel consumption for the entire fleet of about 14.5 miles per gallon, about the same as on the mainland.[12]

Light trucks (less than 10,000 pounds gross vehicle weight) constitute the second largest group of vehicles, numbering about 93,000. While part of this light truck fleet is used, at least part-time, for agricultural and commercial purposes, more than half, if mainland use patterns are any guide, are used for personal transportation. Furthermore, those vehicles in commercial and agricultural service can be expected to be used part-time for personal transportation. Since actual use data are not available for Puerto Rico, light trucks have been classified as personal vehicles.

The total personal vehicle fleet therefore amounts to about three-fourths of a million units. The public transportation vehicle fleet consists of about 2,000 each of buses and taxis and some 13,000 vehicles characterized as for-hire autos and vans. This fleet consists primarily of publicos and other vehicles used in regulated and unregulated urban and intercity public transportation.

The total vehicle fleet of 830,000 vehicles represents a ratio of approximately four persons per vehicle in Puerto Rico as of 1977. In 1965 the vehicle fleet numbered 250,000, for a ratio of 10 persons per vehicle. The Department of Transportation and Public Works estimates that in 1995 the fleet will number approximately 1.5 million, for a ratio of 2 persons per vehicle, about equivalent to that on the mainland at present. This 80 percent growth over 1977 is considerably in excess of that anticipated on the mainland for cars but somewhat less than is anticipated for light trucks. About half the present vehicle fleet is located in the San Juan metropolitan area.

Transportation services are summarized by passenger mode in Table 22. The figures are derived from Office of Energy data, except those for light trucks, for which data on use were not available. It was assumed that light truck fuel economy and annual mileage are similar to those of the passenger-car fleet, and that half the vehicle mileage was attributable to passenger transportation. The balance of light truck use and fuel consumption is included with the "truck and tractor" segment. A little less than two-thirds of the total transportation energy use is in urban areas (mainly San Juan); about 10 percent of this service is provided by public transportation, a proportion close to that of the mainland. Public transportation plays a much more important role in intercity transport, serving about 31 percent of this market (a significantly greater share than on the mainland). Comparable freight transportation statistics are not available, but an approximation of the freight contribution can be made by considering vehicle miles for passenger vehicles. Freight vehicles traveled approximately 0.8 billion miles, or about 8 percent of the total vehicle mileage.

The petroleum consumed in providing these transportation services is disaggregated in Table 23. Three-fourths of the petroleum used for passenger transportation is consumed in urban areas, 92 percent by the private fleet. Freight transportation accounts for 11 percent of total petroleum consumption.

The relationship between transportation services and petroleum consumption may be seen more clearly in Table 24, which is derived from the two previous tables. Intercity public transportation is the most energy-productive, accounting for 13 percent of total passenger miles and consuming only 5 percent of passenger transport energy. Urban public transportation is next, representing 6 percent of passenger miles and 3 percent of energy. Intercity private transportation is next, representing 28 percent of passenger miles and 20 percent of energy. Urban private transportation, which accounts for more than half of the total passenger miles, is least energy productive, consuming almost three-fourths of the total passenger transportation energy.

Table 22 Passenger transportation services, 1977

Mode	Service (billions of passenger miles per year)		
	Urban	Intercity	Total
Personal vehicles			
Private autos	8.9	4.7	13.6
Light trucks	0.5	0.3	0.8
Subtotal	9.4	5.0	14.4
Public vehicles			
Buses	0.2	0.1	0.3
For-hire autos	0.7	2.1	2.8
Taxis	0.05	0.02	0.1
Subtotal	1.0	2.2	3.2
Total	10.4	7.2	17.6

Source: R. Shackson. August 1979. Assessment of Opportunities for Conservation in the Transportation Sector and Strategies for Implementation. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Arlington, Va.: Mellon Institute-Energy Productivity Center.

Projection of Automobile Demand

The future requirements of gasoline for private transportation have been variously linked to the number of vehicles in the fleet, personal income, and yearly purchases of new vehicles. For the purposes of these projections, several assumptions were made. First, the growth in the number of vehicles was obtained from the projections by J. Freyre.[13] Next, yearly vehicle miles per vehicle were reduced by 10

Table 23 Highway transportation energy use, 1977

Mode	Energy use (trillions of Btu)[a]		
	Urban	Intercity	Total
Personal vehicles			
Private autos	53.6	14.2	67.7
Light trucks	3.2	1.1	4.2
Subtotal	56.7	15.2	71.9
Public vehicles			
Buses	0.5	0.2	0.7
For-hire autos	1.4	3.8	5.3
Taxis	0.4	0.1	0.5
Subtotal	2.3	4.1	6.5
Freight vehicles			
Heavy trucks			5.8
Light trucks			4.2
Subtotal			10.0
Total highway transport sector			88.4

[a]Totals do not add due to rounding. Values are converted to Btu's at 5.25 million Btu per barrel for gasoline and 5.80 million Btu per barrel for diesel.

Source: Richard H. Shackson. August 1979. Assessment of Opportunities for Conservation in the Transportation Sector and Strategies for Implementation. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Arlington, Va.: Mellon Institute-Energy Productivity Center.

Table 24 Relative use of energy in passenger transportation

Mode	Percentage of total passenger transport energy	Percentage of total passenger miles
Private		
Urban	72	53
Intercity	20	28
Public		
Urban	3	6
Intercity	5	13

percent to account for the impact on car use of the latest gasoline price increases. This assumption is reasonable in light of the high annual mileage at present. As the ratio of automobiles to population rises, a larger fraction of the fleet will consist of second cars, since there is already a car for every four persons in Puerto Rico. Second cars in general are used less than first cars. Finally, the federally mandated gasoline efficiency standards for automobiles are predicted to have a major impact in total gasoline consumption. By the year 2000, the fleet of automobiles in Puerto Rico is estimated conservatively to average 25 miles per gallon of gasoline. (Under existing law, the mandated average for new autos sold in 1985 stands at 27 mpg, and the turnover of the bulk of the stock is no more than 10 to 12 years.)

The projected gasoline consumption represents a complete break with historical precedent and deserves some discussion. As shown in Table 25, the increase in the number of vehicles is more than offset by the increase in fuel efficiency and the decrease in vehicle miles, resulting in a drop in gasoline demand between 1977 and 1985 of 4 percent and 10 percent in Cases A and B respectively. Continued improvements in efficiency through the year 2000 are expected to offset most growth in the size of the automobile fleet in Case B, resulting in a leveling off of annual gasoline demand at 61 TBtu

Table 25 Automobile energy use

Year	Gasoline consumption (trillions of Btu)	Auto efficiency[a] Miles per gallon	Auto efficiency[a] Btu per vehicle-mile	Growth rate in number of automobiles (percent)[b]	Vehicle miles (billions)	Number of automobiles	Yearly miles per automobile[c]
1977	67.7	14.5	8,621		7.85	660	11,900
1985							
Case A	64.9	17.5	7,143	3.2	9.09	849	10,710
Case B	61.1	17.5	7,143	2.4	8.55	798	10,710
2000							
Case A	73.0	25.0	5,000	3.2	14.6	1,362	10,710
Case B	61.0	25.0	5,000	2.4	12.2	1,135	10,710

[a] Donovan, Hamester, and Rattien, Inc. April 1979. Energy Data for Puerto Rico. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. The efficiency improvements in future years are in line with Federal legislation. Due to the long time horizons in the analysis, it was assumed that Case A and Case B would attain the same average efficiency, despite a slower turnover in auto fleet in a situation of lower economic growth.

[b] Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

[c] Vehicle miles per vehicle decreased by 10 percent in Cases A and B, due to assumed higher gasoline prices and less use of second cars.

between 1985 and 2000. For Case A, between 1985 and 2000 gasoline demand grows at less than 1 percent per year to 73 TBtu which is only 8 percent higher than 1977 use.

The very slow increase in demand for gasoline for automobiles in Case A, and the decrease in Case B, are due mainly to anticipated increases in fuel efficiency. Gasoline consumption in the fiscal year that ended in June 1979 was up 7.2 percent over the same period a year before.[14] The increase in fiscal years 1977 and 1978 averaged 6.8 percent annually.[15] These increases are for total gasoline sales, including trucks and taxis, but taking into account the fact that automobiles in the past have consumed more than 80 percent of the gasoline used on the Island, it is likely that automobile use has increased between 1977 and 1979 at rates near the ones above. (There is no evidence of large increases in the use of trucks, light vans, or taxis.) On the other hand, the price increases of the spring of 1979 were in effect for only 2 or 3 of the 24 months for which the growth rates averaged almost 7 percent. Furthermore, recent analyses that incorporate the effect of $1.00 per gallon gasoline indicate that gasoline demand in the United States as a whole may have peaked and will tend to decrease over at least the next several years.[16] There is considerable uncertainty in the mid-term predictions of gasoline use by automobiles in Puerto Rico. An increase in demand is possible in the near term, followed by a decrease due to efficiency improvements in the automobile fleet. Consumption in the year 2000 will almost certainly not be much higher than at present, and it may be 10 percent or more lower.

Projection of Truck Demand

Growth in freight transportation is linked to the growth in the manufacturing and service sectors of the economy. In Puerto Rico most freight movement is linked to the agricultural and food distribution network, construction, and services such as trade and utilities. The major industrial activities, refining and petrochemicals, do not have large trucking requirements except for transport of gasoline to retailers. The growth of freight transportation is thus linked to the growth of the commercial sector and of selected manufacturing activities such as food processing and cement production. Table 26 summarizes the results of the projection.

Projection of Air Demand

It appears that most of the jet fuel consumed in Puerto Rico is used by flight leaving Puerto Rico, and the projections of energy demand link the growth in demand for jet fuel with estimates of the number

Table 26 Energy use by trucks

Year	Energy consumption (trillions of Btu)					Annual growth rate, freight[b] (percent)	Energy intensity factor[c]
	Freight			Light trucks passenger mode[a]	Total energy consumption by trucks		
	Heavy trucks	Light trucks	Total truck freight				
1977	5.8	4.2	10.0	4.2	14.2	--	1.0
1985							
Case A			13.7	5.4	19.1	4.0	1.0
Case B			12.5	5.1	17.6	2.8	1.0
2000							
Case A			19.0	8.7	27.7	3.73	0.80
Case B			14.5	7.2	21.7	2.53	0.80

[a] The proportion of light trucks used as passenger vehicles is estimated to grow at the rate of growth of the automobile vehicle fleet. No improvement in their efficiency is expected.

[b] It is assumed that the growth in ton-miles of freight transportation follows the growth rate of GDP for all cases (Tables 10-13).

[c] Refers to the relative energy consumed per ton-mile of freight transport, with 1977 consumption set at 1.0.

of visitors to the Island.[5] This ignores, however, the fact that much of the air traffic demand stems from travel by Puerto Rico residents to and from the United States. Another factor affecting future demand for jet fuel is the growth in air freight, for which no information was obtained. Aviation fuel sales were stable in the mid-1970's but increased sharply in 1977 (see Table 7). The results of the projections are presented in Table 27.

Table 27 Aviation fuel use

Year	Aviation fuels (trillions of Btu)	Index (1977 = 100)	Annual growth rate (percent)[a]
1977	14.2	100	
1985	18.3	129	3.25
2000	26.6	187	2.5

[a]Only one set of growth rates (for both freight and passenger trucks) is used because growth in the number of visitors is independent of economic factors in Puerto Rico; the impact of growth in air freight is difficult to quantify.

Source: Adapted from Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

Projection of Public Transportation Fuel Demand

Nearly 90 percent of the fuel used by this subsector is used by publicos and taxis in urban and intercity travel; the rest is consumed by buses. No time series information is available for publicos and taxis, but it would appear that high gasoline prices will increase their use. Several recent reports[17] select high-occupancy van or automobile "mass transit" systems over buses or trains as the inherently least costly mode. A sustained growth rate of 4 percent perannum was thus applied to the 1977 number of passenger miles in this subsector. The energy intensity of the sector (Btu per passenger mile) was projected to decrease by 14 percent by 2000. This results in a total demand of 12.3 TBtu in 2000 (Table 28).

Table 28 Fuel use for buses, "publicos," and taxis

Year	Fuel (trillions of Btu)				Index (1977 = 100)[a]	Energy intensity factor[b]
	Gasoline	Diesel (bus)	Kerosene (bus)	Total		
1977	5.8	0.3	0.4	6.5	100	100
1985	7.9	0.4	0.5	8.8	137	100
2000	12.3	1.3	--	13.6	246	86

[a]Service levels (passenger miles traveled) are assumed to increase at a rate of 4 percent per year.

[b]Corresponds to relative energy use per passenger mile.

Bus ridership data exist only for the San Juan Metropolitan Bus Authority. Ridership declined by 40 percent between 1970 and 1977, but fuel consumption nevertheless increased 19 percent during this period.[18] This is caused by an erosion in load factor and indicates that passengers have increasingly chosen other modes of transportation during the last decade. The growth in future bus demand for fuel is thus likely to be low, and bus usage is slight compared with other public transport modes. Thus no separate projection was made for them.

Summary of Transportation Sector Projections

Table 29 contains the summary projections for transportation. (Ships were not included in these projections for lack of reliable information.) The projected annual growth rate for the sector is moderately low (1.6 percent in Case A and 1.0 percent in Case B for the 1985-2000 period, and less than 1 percent in the years up to 1985), with whatever increase in demand for fuel coming from modes other than the private automobile.

Table 29 Summary, transportation sector fuel use

Mode	Consumption (trillions of Btu)				
	1977	1985		2000	
		Case A	Case B	Case A	Case B
Automobile	67.7	64.9	61.1	73.0	61.0
Trucks	14.2	19.1	17.6	27.7	21.7
Public transportation	6.5	8.8	8.8	13.6	13.6
Aviation	14.2	18.3	18.3	26.6	26.6
Total	102.6	111.1	105.8	140.9	122.9

Industrial and Commercial Sector

For purposes of energy analysis these projections include in the industrial and commercial sector projections of the energy used in manufacturing, agriculture construction, trade, finance, and government and other services. Table 30 shows how those elements of the economy have developed since 1950 and how much they now contribute to the Island's gross domestic product. The manufacturing sector has grown and diversified over the last few decades and now represents 35 percent of GDP (meanwhile agriculture has declined from almost 20 to less than 3 percent). A variety of activities now constitute the manufacturing sector; most important are the food, apparel, machinery, petrochemical, and pharmaceutical industries.

It is interesting to note that, despite its importance in the energy situation on the Island, petroleum refining contributed only about 1 percent to domestic product in 1977 and less than 0.5 percent of employment. Even the petrochemical industry's contributions to total GDP and employment were only 2 percent and 1 percent respectively. Pharmaceuticals, on the other hand contributed 9 percent of total GDP. Table 31 summarizes the contributions of various industries to the manufacturing sector. We include in the commercial sector a variety of energy consuming activities in retail trade, financial institutions, services, and government.

The consumption of fuels and electricity in industry and commerce depends on the level of the activity and on the particular processes or technologies used. Projected total energy consumption consequently grows at a rate related to the growth in output for that sector, corrected for any anticipated change in overall energy efficiency. In light of rising energy prices and opportunities for conservation, it is expected in general that energy consumption will grow in Puerto Rico more slowly than output in any given economic activity.[19]

The Office of Energy is analyzing the use of fuels by specific manufacturing activities in Puerto Rico. A summary of the preliminary findings of that analysis is presented in Table 32, where each industry's fuel consumption is compared with its contribution to GDP. The very large variations in energy intensity of direct use of fuels are noteworthy. Consumption of electricity by different industrial activities also shows extreme variations: three subsectors, pharmaceuticals, cement and petroleum refining-petrochemicals, use about 60 percent of the total sold to industrial customers.

Projection of Direct Fuel Demand

The future demand for fuels by the industrial and commercial sector has been projected at one overall growth rate, because there is no detailed breakdown of past use beyond the preliminary data from the above-mentioned survey, which covers only manufacturing. Data for agriculture, construction, government, and all service sectors are unavailable.

Total consumption of petroleum products in the industrial and commercial sector was estimated at 84.6 TBtu for 1977. This amount reflects sales of fuels by the petroleum industry in Puerto Rico (internal consumption in Figure 5), and thus excludes all fuel used within refineries and fuels and feedstocks used in the petrochemical industry.

To obtain the estimate of oil use by refineries and the petrochemical industry, which is not reported in any published source, a calculation was made of the difference between total imports and the total of exports plus "internal consumption." For 1977, of the 450.7 TBtu (77.7 million barrels) of imported crude an estimated 28.0 TBtu was consumed in the refining process. (About 6 percent of refining inputs are used as refinery fuel.) The petrochemical sector consumed on the order of 144 TBtu of which 68.7 TBtu (11.8 million barrels) were exported as aromatics, naphtha, and lubricating oils, and the remainder was transformed into chemicals such as olefins or further elaborated into paints, textiles, and similar products. A part of this total energy flowing through the petrochemical sector was used to raise steam and provide heat for chemical reactions; there is no reliable information on the size of this fraction. The

Table 30 Gross domestic product by major industrial sector: selected fiscal years, 1950-1978, in millions of dollars

Item	Fiscal year					
	1950	1960	1970	1973	1975	1978
Gross domestic product	723.9	1,691.9	5,034.7	7,030.4	8,207.7	10,902.5
Agriculture	132.1	164.0	160.9	175.5	264.9	302.8
Manufacturing	119.7	366.3	1,190.0	1,879.2	2,309.8	3,784.6
Contract construction and mining	30.4	101.1	379.1	485.2	464.6	339.0
Transportation and other public utilities	61.2	155.8	439.3	596.4	762.9	969.2
Trade	144.3	319.1	898.3	1,226.4	1,349.7	1,809.5
Finance, insurance and real estate	74.5	197.7	613.8	826.3	873.9	1,110.1
Services	44.7	140.9	512.2	666.3	833.7	1,140.7
Government	75.1	187.1	609.9	1,029.3	1,333.5	1,558.5
Commonwealth	67.4	155.6	542.1	911.6	1,144.6	1,305.8
Municipalities	7.7	31.5	67.8	117.7	188.8	252.6
Statistical discrepancy	41.9	60.0	231.2	146.0	14.6	-111.9
	Percentage distribution					
Gross domestic product	100.0	100.0	100.0	100.0	100.0	100.0

Agriculture	18.2	9.7	3.2	2.5	3.2	2.8
Manufacturing	16.5	21.6	23.6	26.7	28.1	34.7
Contract construction and mining	4.2	6.0	7.5	6.9	5.7	3.1
Transportation and other public utilities	8.4	9.2	8.7	8.5	9.3	8.9
Trade	19.9	18.9	17.8	17.4	16.4	16.6
Finance, insurance and real estate	10.3	11.7	12.2	11.8	10.6	10.2
Services	6.2	8.3	10.2	9.5	10.2	10.5
Government	10.4	11.0	12.1	14.6	16.2	14.3
Commonwealth	9.3	9.2	10.8	13.0	13.9	12.0
Municipalities	1.1	1.9	1.3	1.7	2.3	2.3
Statistical discrepancy	5.8	3.5	4.6	2.1	0.2	-1.0

Source: Puerto Rico Economic Development Administration, Planning Board, as compiled in Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

Table 31 Percentage distribution of manufacturing gross domestic product by industrial sector: selected fiscal years, 1950-1978

Standard industrial classification (1972)	Industrial sector	Fiscal year								
		1950	1960	1970	1973	1974	1975	1976	1977	1978
31	Leather products	(a)	2.0	3.0	1.7	1.6	1.5	1.2	1.0	1.1
23	Apparal and related products	14.7	14.1	14.7	10.8	10.1	9.1	9.0	8.4	8.1
22	Textile mill products	1.0	4.0	3.8	2.9	2.7	2.3	1.5	1.4	1.2
24, 25	Wood products and furniture	3.6	2.5	2.3	1.8	1.4	1.2	1.0	0.9	0.9
21	Tobacco products	4.3	3.3	6.5	5.1	4.8	5.0	4.3	3.6	3.3
	Subtotal	23.6	25.9	30.3	22.4	20.6	19.1	17.0	15.3	14.6
30	Rubber and plastic products	0.5	1.6	1.7	1.4	1.5	1.4	1.5	1.4	1.4
20	Food and related products	58.6	34.5	24.8	20.2	18.1	19.2	17.7	15.7	17.6
39	Miscellaneous manufacturing	0.7	2.2	2.1	1.3	1.4	1.4	1.5	1.4	1.3
38	Professional and scientific instruments	0.3	2.2	3.2	4.0	3.8	4.2	4.9	5.0	5.2
36	Electrical machinery	1.2	7.5	8.4	10.0	10.5	10.5	10.3	11.5	11.5
284, 285, 287, 289	Other chemical products	0.3	0.2	0.6	0.7	0.4	0.4	0.6	0.9	0.6
	Subtotal	61.6	48.2	40.9	37.6	35.7	37.2	36.5	35.9	37.7

32	Stone, clay, glass and concrete, products	4.8	6.4	4.9	4.5	4.0	3.9	2.8	2.7	2.7
35, 37	Machinery, except electrical, and transportation equipment	0.2	1.7	1.4	2.3	2.5	2.8	3.0	4.0	3.7
33, 34	Metal products	0.7	4.2	4.0	4.0	4.3	4.1	3.1	2.8	2.6
26, 27	Paper products, printing and publishing	2.8	4.8	3.1	2.3	2.5	2.5	2.1	2.0	2.0
283	Drug products	3.1	2.2	8.0	16.8	17.2	21.9	23.1	26.1	27.3
281, 282, 286	Petrochemical products	1.4	1.0	1.6	3.4	5.0	4.5	8.7	7.6	6.2
29	Petroleum refining and related products	1.8	5.6	5.8	6.7	8.2	4.0	3.7	3.5	3.1
	Subtotal	14.8	25.9	28.8	40.0	43.7	43.7	46.6	48.7	47.7
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a]Not available

Source: Puerto Rico Economic Development Administration, Planning Board, as compiled in Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

Table 32 Direct fuel use by industry, 1977

Standard industrial classification	Industry	A Fuel consumed (thousands of barrels)[a]	B GDP (millions of dollars)[b]	C (A ÷ B)
22, 23	Textiles, apparel and related products	48.2	325.4	0.15
21	Tobacco products	5.2	121.3	0.04
20	Food and related products	749.9	521.1	1.44
38	Professional and scientific instruments	4.8	165.3	0.03
36	Electrical machinery	779.4	381.7	2.09
32	Stone, clay, glass and concrete products	1,839.9	89.6	20.53
33, 34	Metal products	208.1	94.4	2.20
26, 27	Paper products, printing and publishing	369.7	64.9	5.70
283	Drug products	1,137.2	866.1	1.31
281, 282, 286	Petrochemical products	1,140.7	253.5	4.50
29	Petroleum refining and related products	4,828[c]	117.8	40.98
	Other	57.9	317.9	0.18
	Total	11,189.0	3,319.0	3.37

[a]Preliminary Results, Puerto Rico Office of Energy, Survey of manufacturing energy use, October 1977.

[b]Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. See also Table 31.

[c]Estimated from refinery throughput; see the section of this chapter entitled "Current Energy Supply."

matter is further complicated by the fact that the firms are integrated; for example, the main refinery, CORCO, is also a major petrochemical industry.

Demand for fuels by the aggregated industrial and commercial sector is projected to grow until 1985 at an overall rate of 3.0 percent in Case A and 1.8 percent in Case B (lower than the estimated GDP growth rates of 4.0 percent and 2.8 percent for Cases A and B respectively). The growth rates for the period 1985-2000 are estimated at 2.7 percent in Case A and 1.5 percent in Case B, similarly based on higher GDP growths of 3.7 percent and 2.5 percent respectively. We have thus assumed that industrial fuel consumption will grow at a rate 1 percent per year lower than the growth in GDP. This is consistent with recent experience in the United States.[19] Table 33 shows the projected demand for petroleum products in the year 2000.

Projections of Industrial and Commercial Electricity Demand

The future demand for electricity is estimated on the basis of assumed growth rates for several manufacturing industries (refining and petrochemicals, pharmaceuticals, and cement). The rest of the industrial sector and the entire commercial sector are described by a single overall growth rate.

In the refining and petrochemicals industries, with their highly uncertain outlooks, it was assumed that electricity demand will grow at an average annual rate of 1.0 percent. The basis of the projection in Case A is adjusted according to the assumption that the chloralkali plant of PPG Industries Caribe will not reopen. Case B assumes in addition that the Oxochem, Puerto Rico Olefins, and Caribe Isoprene facilities will not resume operations. Growth in these industries is linked to the domestic Puerto Rican demand for petroleum products from refineries; Freyre[5] has tentatively projected the output of refineries as increasing by 2 percent per annum in 1978-85, with the growth rate declining to 1.5 percent for the rest of the planning period. The Puerto Rican petrochemical industry is highly dependent on mainland markets; our economic forecast suggests a slow growth without quantifying what it could be.

For the parmaceutical industry the assumption is that demand for electricity grows at the same rate as output, estimated by Jorge F. Freyre[20] to be 9.3 percent per annum for 1978-85 and 6.5 percent per annum for 1985-2000 (Case A). For Case B, growth rates of 6.5 percent and 4.6 percent were assumed for the two periods respectively.

Electricity demand for the cement industry grows at the rate of growth of output of the stone, clay, glass and concrete products industry, estimated by Freyre[20] to be 1.2 percent and 1.7 percent annually for the two periods analyzed in Case A and 0.8 percent and 1.3 percent respectively for Case B.

Table 33 Industrial and commercial fuel demand

Time period/ year	Consumption (trillions of Btu)			Growth rate (percent per year)			
				GDP[a]		Energy[b]	
	1977	Case A	Case B	Case A	Case B	Case A	Case B
1977	84.6						
1977-1985				4.0	2.8	3.0	1.8
1985		107.2	97.6				
1985-2000				3.7	2.0	2.7	1.5
2000		159.9	122.0				

[a] Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Tables 44, 54.

[b] See note 19.

Growth rates corresponding to those of GDP are applied to the remainder of industry. These are the same as those used for petroleum demand in industry (Table 33), except that in the case of electricity no allowance is made for improvements in efficiency. This is not because savings in the use of electricity in industrial processes are unavailable, but because they are likely to be countered by the adoption of new electricity-consuming processes and activities.

Demand for electricity in the commercial sector (comprising trade, financial services, insurance and real estate services, and government) is projected at the rate of growth of output for this sector--3.4 percent annually through 2000 for Case A and 2.4 percent in 1978-85 and 2.2 percent in 1985-2000 for Case B.[5] Table 34 summarizes the electricity demands projected by these means. For the industrial and commercial sectors combined, total demands of 30.6 TBtu (8,950 million kWh) in 1985 and 50.4 TBtu (14,800 million kWh) in

Table 34 Industrial and commercial electricity consumption

Subsector	Consumption								
	1978[a]	1985				2000			
	(trillions of Btu)	Annual growth rate, 1978-85 (percent)		(trillions of Btu)		Annual growth rate, 1985-2000 (percent)		(trillions of Btu)	
		Case A	Case B	Case A	Case B	Case A	Case B	Case A	Case B
Pharmaceuticals	1.7	9.3	6.5	3.17	2.64	6.5	4.6	8.15	5.18
Oil refining and petrochemicals[b]	7.97								
Case A	(6.26)	1.0	-	6.71	-	1.0	-	7.79	-
Case B	(5.49)	-	1.0	-	5.89	-	1.0	-	6.84
Cement	0.68	1.2	0.8	0.74	0.72	1.7	1.3	0.95	0.87
Other industry	6.37	3.7	2.7	8.38	7.7	3.7	2.5	14.45	11.15
Commercial	9.15	3.4	2.4	11.56	10.80	3.4	2.2	19.09	14.97
Total	25.90	2.4	1.0	30.56	27.75	3.4	2.3	50.43	39.01

[a] Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Table 60.

[b] The refining and petrochemicals figures in parentheses refer to the demand of these industries, excluding that of the PPG Industries Caribe chloralkali plant in Case A (some 500 million kWh) and excluding in addition the demand of the Oxochem, Puerto Rico Olefins, and Caribe Isoprene facilities in Case B (some 275 million kWh).

Table 35 Summary of Puerto Rican energy demands

	Demand (trillions of Btu)				
	1977	1985		2000	
		Case A	Case B	Case A	Case B
Industrial and commercial electricity	25.1	30.56	27.75	50.43	39.01
Residential electricity	11.8	15.88	14.90	26.75	21.14
Total electricity[a]	38.3[b]	46.44	42.65	77.18	60.15
Oil to electricity[c]	134.7	154.8	142.2	257.3	200.5
Oil to residential	3.5	3.6	3.5	4.6	4.2
Oil to transportation	102.6	111.1	105.8	140.9	122.9
Oil to industrial and commercial[d]	84.6	107.2	97.6	159.9	122.0
Total petroleum fuels	325.4	376.7	349.1	562.7	449.6
Petroleum use for nonenergy products (4.5 percent)	16.4	16.9	15.7	25.4	20.2
Total internal consumption[d,e]	341.8	393.6	364.8	588.1	469.8

[a]This total omits public lighting, which the Electric Power Authority forecasts to decrease gradually to 140 million kWh (less than 0.5 trillion Btu) by 1983.

[b]Total includes 1.4 trillion Btu of "other uses." The 1978 electricity consumption by the industrial and commercial sector, actually used as the basis for projection, was 25.9 trillion Btu.

[c]The continued generation of electricity by oil postulated here is for illustrative purposes only. Planning for Puerto Rico's first coal steam power plant is underway at several stages within the Electric Power Authority, and other sources such as ocean thermal energy conversion are under consideration also. The projection incorporates a 6 percent decrease in generation and distribution losses; for this reason the increase in the "oil to electricity" total is proportionately less than that in "total electricity".

[d]Excluding use by refineries and petrochemical plants

[e]This amount corresponds to the Office of Energy's definition of "internal consumption."

2000 are obtained for Case A, and 27.8 TBtu (8,100 million kWh) and 39.0 TBtu (11,400 million kWh) in 1985 and 2000 respectively for Case B.

The latest Electric Power Authority forecasts to 1983[21] have been extrapolated at the respective 1982-83 growth rates for the industrial and commercial sectors. This calculation yields a total demand in 1985 by these two sectors of 9,292 million kWh, which is nearly 4 percent higher than our Case A and a substantial 15 percent higher than our Case B. The difference is not surprising in light of this committee's assumptions about the future of the refining and petrochemical industry, which weigh heavily in the totals. The Aughority eliminates only two plants in its estimates (one of which, however, is the PPG Industries Caribe chloralkali plant, the largest electricity consumer in the group of closed plants), while our Case B projections assume four permanent shutdowns. The Authority's projections are in fact significantly different from this committee's only in the low growth case, the basic assumptions of which are not consistent with those implied by the authority's projections.

Summary of Demand Projections

Projections of energy demand for the residential, transportation, and industrial and commercial sectors include demands for only two energy forms, electricity and petroleum products, omitting energy sources not extensively used at present, such as coal, biomass, and solar energy. The potentials of these alternative energy sources are the subject of Chapter 7.

The sum of the projected energy demands in the residential, transportation, and industrial and commercial sectors (Table 35) corresponds to what the Office of Energy classifies as internal consumption of energy in Puerto Rico. That is, it leaves out petroleum product exports, internal consumption in refineries and petrochemical complexes, and chemicals manufactured from imported and domestically produced naphtha. To project total crude oil and naphtha import requirements, one must make explicit assumptions about the future demand for fuels and chemicals on the mainland and, more important, the competitiveness of Puerto Rican products vis-a-vis supplies on the mainland Gulf Coast and in the rest of the world.

In Table 35, projections of internal consumption of petroleum products for 1985 and 2000 are computed on the assumption that electricity generation continues to be based exclusively on petroleum. This is done for illustrative purposes only, in recognition of the Puerto Rico Electric Power Authority's consideration of a coal-fired generating unit. (See Chapter 5.)

To convert electricity demand into fuel requirements, a factor of 0.15 was assumed for transmission and distribution losses and internal use by the utility, and a factor of 0.35 for power plant efficiency. The results of the projection show that the fraction of total petroleum fuels represented by oil inputs to electric generation remains stable between 1977 and 1985 (about 41 percent of the total) but increases slightly (to 45-46 percent) by the year 2000. (See Table 36.) This underscores the importance of fuel substitution in electricity generation.

The Puerto Rico Electric Power Authority forecasts electricity generation in fiscal 1985 at 16,991.4 million kWh.[21] The corresponding values for that year in this committee's projection are 16,008 million kWh in Case A and 14, 702 million kWh in Case B, assuming that generation and demand differ by 15 percent, to account for losses in transmission and distribution. For our Case A, which is based on assumptions similar to those used by the Authority in tis projections, the results are within 6 percent of each other. In Case B, the projected pattern of slower economic growth yields an estimate of total electricity generation that is 13.5 percent lower than the Authority's.

Table 36 shows the projected annual growth rates for petroleum demand by all sectors. Demand grows faster between 1985 and 2000 than between 1977 and 1985, in part because of growth in electricity demand by industry. The demand for electricity in the residential and commercial sectors grows at an approximately constant rate throughout the projection years; only in the industrial sector does electricity demand experience faster growth in the later period. This is caused by the assumed sustained high growth in the pharmaceutical industry, which in Case A jumps from 10 percent of total industrial electricity consumption in 1977 to a projected 27 percent in 2000 (Table 34). The higher growth rate in oil demand in the 1985-2000 period is also due in part to the character of the transportation sector demand; vehicle miles driven per automobile are assumed to drop before 1985 due to higher fuel prices, but to stabilize thereafter. (The projection does not incorporate further decreases in vehicle miles per year in response to increasing gasoline prices). The factors mentioned here show the sensitivity of the overall projections of petroleum requirements to individual assumptions made about subsectoral growth rates.

A final tabulation of total crude and naphtha import requirements is presented in Table 37. Excluded from this table is use of feedstocks by petrochemical companies. Despite explicit assumptions for Case A and Case B on reopenings of these plants, there are no data on their individual inputs of raffinate, naphtha (imported directly or obtained from domestic refineries), and other feedstocks. For all other petroleum requirements, according to these projections, Puerto Rico will import 118 to 123 million barrels in 1985 and 137 to 159 million barrels by the year 2000. Internal consumption of petroleum is expected to increase to 63 to 68 million barrels per year by 1985 and to 81 to 102 million barrels in 2000, from the current level of 59 million barrels. Even at current prices for crude oil, that implies oil import costs in excess of 2 billion dollars by the year 2000.

Table 36 Petroleum demand, growth rates, and sectoral breakdown

Consuming sector	Annual growth rate (percent)				Sectoral breakdown (percent)				
	1977-1985		1985-2000		1977	1985		2000	
	Case A	Case B	Case A	Case B		Case A	Case B	Case A	Case B
Electricity generation	1.8	0.7	3.4	2.3	41.4	41.0	40.7	45.7	44.6
Residential sector	0.0	0.0	1.6	1.2	1.1	0.9	1.0	0.8	0.9
Transportation sector	1.0	0.4	1.6	1.0	31.5	29.5	30.3	25.0	27.3
Industrial and commercial sector	3.0	1.8	2.7	1.5	26.0	28.5	28.0	28.4	27.1
Total petroleum requirements	1.8	0.9	2.7	1.7	100.0	100.0	100.0	100.0	100.0

Table 37 Total petroleum import requirements

	Millions of barrels per year				
	1977	1985		2000	
		Case A	Case B	Case A	Case B
Internal consumption	59	68	63	102	81
Petroleum fuels exports[a]	35	38	38	38	38
Aromatics, naphtha, and other petroleum product exports[b]	12	12	12	12	12
Fuel use in refineries[c]	4.5	5.1	4.8	6.7	5.7
Other chemical feed-stocks produced or imported	13	(d)	(d)	(d)	(d)
Total imports (crude and feed-stocks)	123	123[e]	118[e]	159[e]	137[e]

[a]This includes gasoline, residual oil, and middle distillates.

[b]Assumes that the market for aromatics continues to be favorable and Puerto Rico producers can remain competitive

[c]Increases at the rate of production of petroleum products

[d]Unknown

[e]Excludes requirements of Union Carbide and all other petrochemical concerns that may operate again in the future

NOTES

1. Office of Petroleum Affairs. April 1977. Synopsis of the Energy Situation of Puerto Rico, 1976. San Juan: Office of the Governor of Puerto Rico. p. 47.

2. Oficina de Energia. November 1978. Estadisticas Sobre el Petroleo y sus Productos Ano Natural 1977. San Juan: Oficina del Governador de Puerto Rico.

3. Merrill Lynch White Weld Capital Markets Group. October 1979. $100,000,000 Puerto Rico Water Resources Authority Power Revenue Bonds, Series F. Official Statement.

4. In 1977 total electricity generated was 13,291,000 kWh. Of this, 809,000 were used for in-plant auxiliary equipment, the net generation being 12,482,000 kWh. Trnasmission and distribution losses were 1,252,000 kWh, or about 10 percent of net generation.

5. Jorge F. Freyre. July 1979. Long Term Projections of the Puerto Rican Economy. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

6. Freyre, Long Term Projections (note 5), p. 79-81.

7. Donovan, Hamester, and Rattien, Inc. April 1979. Energy Data for Puerto Rico. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. p. 2. This source states that 30 to 40 percent of households use gas for cooking. The 1970 U.S. Census of Housing indicates that 49 percent of all year-round occupied housing units use gas for cooking. A sample of 605 households in the San Juan metropolitan area shows 37.5 percent of PREPA customers having gas ranges in 1978; the survey results, however, are not representative of the entire Island.

8. Data from PREPA indicate that 55 percent of their customers use less than 300 kWh per month; a large fraction of these customers have other appliances, including water heaters, which makes it unlikely that their cooking is also electric. PREPA estimates cooking consumes 100 kWh per month. The San Juan Area Survey cited in note 7 shows a total of 59 percent of the households surveyed use electric ranges. The 1970 census indicates 29 percent use electricity as a fuel for cooking; among other factors, all new public housing in recent times has been electric, so that the 1970 saturation would be expected to increase substantially.

9. A survey of low income population in 1976 indicates that about 14 percent of the sample use charcoal for some household purposes. (Donovan, Hamester, and Rattien, Energy Data (note 7).)

10. Monthly kilowatt hour usages per appliance are taken from PRWRA, cited in Donovan, Hamester and Rattien, Energy Data (note 7), p. 18-20.

11. U.S. Department of Transportation. 1975. Selected Highway Statistics. Washington, D.C.; Puerto Rico Department of Transportation and Public Works. 1978. Energy and the Puerto Rican Economy. San Juan. p. 40.

12. This estimate was made by an analysis of the composition of the private passenger car fleet in Puerto Rico. (See Norma Ayuso and Carlos R. Vizcarrondo. August 1978. A Profile of the Private Passenger Car Fleet in Puerto Rico and Its Average Fuel Economy. Research Report No. 1. San Juan: Office of Energy of Puerto Rico.)

13. Freyre, Long Term Projections (note 5), ch. 4.

14. Jorge F. Freyre. Personal communication to John Berga. September 19, 1979.

15. Puerto Rican Department of Transportation and Public Works, Office of Economics and Statistical Studies. Cited in Donovan, Hamester, and Rattien, Energy Data (note 7), Section D1.

16. Anthony J. Parisi. September 16, 1979. The End of an Era: Gas Consumption Peaking. New York Times. Sec. 3, p. 1.

17. See, for example, National Research Council. 1979. Alternative Energy Demand Futures to 2010. Committee on Nuclear and Alternative Energy Systems, Demand and Conservation Panel. Washington, D.C.: National Academy of Sciences. ch. 5.

18. Office of Energy. 1978. Statistical Compendium on Energy Use for Internal Transportation in Puerto Rico--1977. San Juan: Office of the Governor of Puerto Rico. Table 6.

19. During the period 1973-78, industrial output in goods and services rose 12 percent, while industrial use of energy dropped by more than 10 percent--roughly a 22 percent overall improvement in energy productivity (Roger W. Sant. 1979. The Least Cost Energy Strategy--Minimizing Consumer Costs Through Competition. Arlington, Va.: Mellon Institute.) See also U.S. Department of

Continued

Energy. 1977-78. Voluntary Industrial Energy Conservation. Progress Reports 5, 6. Washington, D.C. (DOE/CS-0035; DOE/CS-0018). All indications are that the current energy price increases, which are not yet reflected in available statistics, will improve efficiency in energy use.

20. Unpublished projections of manufacturing gross product by Jorge F. Freyre, consultant to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

21. Vilma Arias. August 1979. Forecasting and Cost of Service Section, PRWRA: Memorandum. San Juan: Puerto Rico Water Resources Authority.

4 THE OIL REFINING AND PETROCHEMICAL INDUSTRIES

The refining industry in Puerto Rico was developed, beginning in the late 1950's, to import crude oil at relatively low world prices and sell products at higher domestic prices, on the Island and on the mainland. As long as world crude oil prices were below domestic prices (which were insulated by the import quota system) refiners on the Island were able to turn a good profit from the difference and also pay the higher transportation costs to the mainland that resulted from the Jones Act (46 U.S.C. 883), which requires that goods traveling by water between U.S. ports move in U.S.-registered ships.

From Puerto Rico's point of view, the refining margin defrayed the cost of refined products used on the Island for power generation and transportation; the exported products had a net value about equal to the landed cost of the crude. But the reversal of the price relationships between foreign and domestic crude after 1973 changed Puerto Rico's advantages to disadvantages; allocations of entitlements to Puerto Rican refineries have helped to alleviate the problem but have not solved it.

The change in price relationships also led to difficulties for some petrochemical operations on the Island. The Commonwealth Oil and Refining Corporation (CORCO) had entered into joint ventures with PPG Industries Caribe and W. R. Grace for the production of olefin derivatives, becoming highly levered in the process as its debt load quadrupled. It could not pass along the escalation on feedstock costs because of fixed-price contracts with its joint-venture partners, Puerto Rico Olefins and Oxochem. The results were rapidly mounting losses for CORCO, and eventual bankruptcy. CORCO is also reported to have suffered from management problems before its bankruptcy. Some other petrochemical ventures on the Island seem to have escaped most of these difficulties.

The major changes in petrochemical feedstock prices in the mid-1970's came before the Island's petrochemical complex had attained an optimum structure, and coincided with the 1974-75 worldwide recession, which caused a slump in demand for petrochemicals. In addition, electric costs on the Island escalated well above those of mainland plants. These events discouraged further investment in downstream petrochemical facilities, made the PPG Industries Caribe chloralkali plant (which produces chlorine and caustic soda) uneconomical and arrested the development of the CORCO-PPG complex before downstream balance had been achieved. As a result, much of Puerto Rico Olefin's (PRO) potential ethylene production could not be used within the CORCO-PPG complex or anywhere else on the Island; technical and economic obstacles have discouraged development of an export market for this olefin. Again, some other petrochemical producers in Puerto Rico do not appear to suffer from these problems to nearly the same degree.

THE OUTLOOK

The question before us is whether and in what ways these industries are likely to affect and be affected by the supply and use of energy on the Island. Because CORCO is Puerto Rico's biggest refiner and has been involved with a very large petrochemical complex, its problems and those of its joint ventures have a major bearing on the future supply and demand of energy. Figure 7 is a schematic diagram of CORCO's previous complex relationships with major fuel and petrochemical consumers, including its own joint ventures. The figure shows the principal facilities in the Island's refining and petrochemical industries, the patterns of ownership, and the flows of fuels, feedstocks, and products. Puerto Rico Olefins and Oxochem are currently shut down, as are the PPG Industries Caribe, Caribe Isoprene, and Air Products facilities.

Refining

Puerto Rico's total refining capacity in 1978 was rated at 266 thousand barrels per day, distributed among CORCO (the largest complex with a capacity of 141 thousand barrels per day), Yabucoa Sun, Caribbean Gulf Refining Co., and a very small operation by Peerless Petrochemicals. Production in 1977 was 231 thousand barrels per day. Crude oil imports were 213 thousand barrels per day.

Internal demand for refined petroleum in 1977 was about 135 thousand barrels per day; 75 thousand was for residual fuel oil, 43 thousand for gasoline, and the remainder for distillate fuel oil and

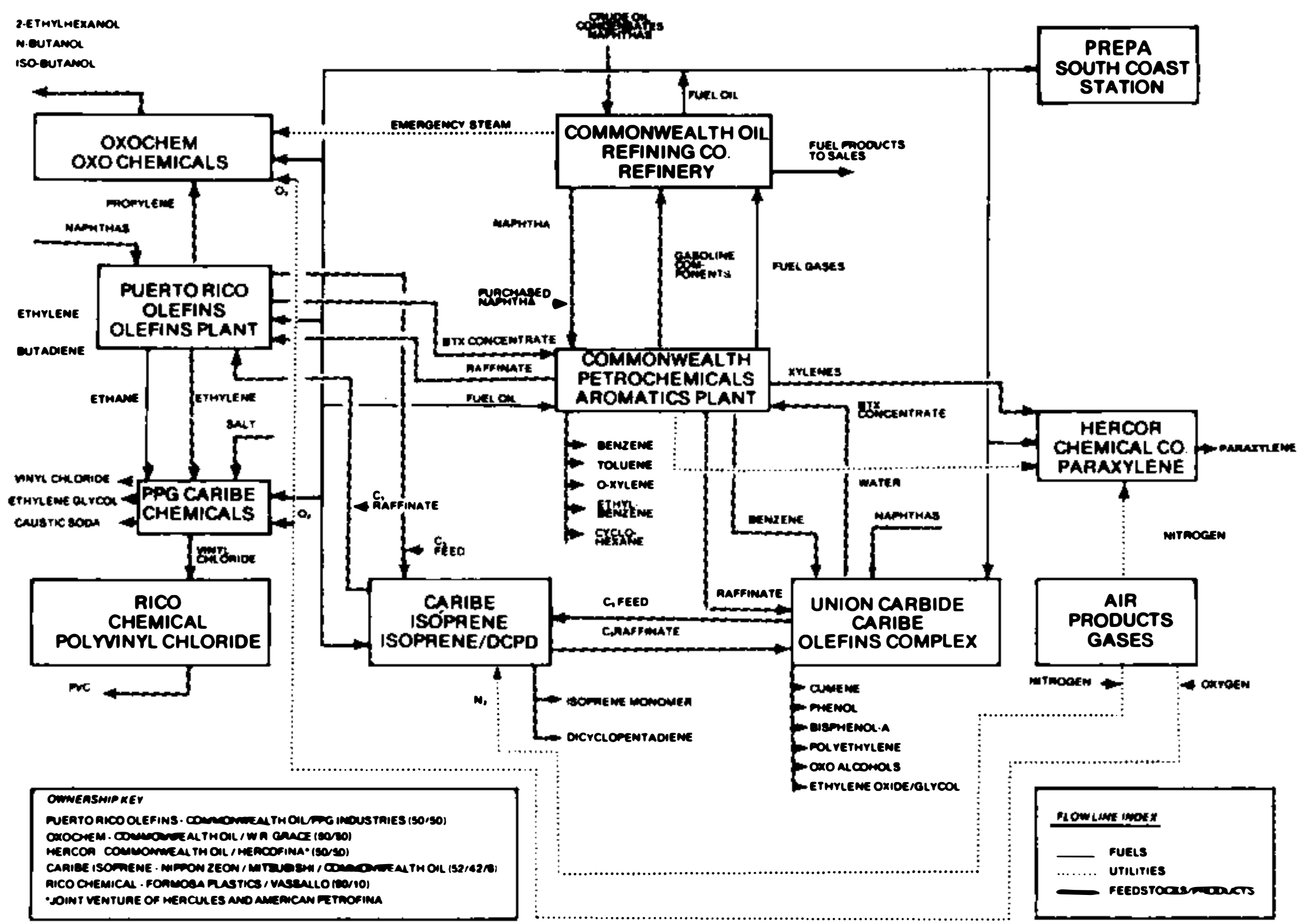


Figure 7 Puerto Rican petrochemical complex: fuels, utilities, feedstocks, and products (Commonwealth Reorganization Company, Inc. December 1978. First Phase Report to Commonwealth Oil Refining Company, Inc., the United States District Court for the Western District of Texas, and the Creditors' Committee. p. 49.)

minor products. Local demand in Puerto Rico is and will continue to be the principal claimant for products refined on the Island. The remainder of refined-products output (some 96 thousand barrels per day in 1977) was exported, almost all of it to the U.S. mainland. Of this total, more than 50 percent was gasoline, 40 percent middle distillates, and about 10 percent residual fuel oil.

In addition to the crude oil imports of 213 thousand barrels per day, the Island imported 116 thousand barrels per day of naphtha. Part of this naphtha was refined into finished petroleum products and part was used as feedstock in the petrochemical industry. The oil refiners on the Island also produced naphtha that was used in some petrochemical plants. CORCO produced about 10 percent of the naphtha needed in its refining operations. CORCO's share of 1977 output was 130 thousand barrels per day, or 56 percent. CORCO shipped 89 thousand barrels per day to Puerto Rican users and exported 41 thousand barrels per day. In 1978 it continued to ship over two-thirds of its output to Island customers.

Future Markets and Competitors

The Puerto Rican refineries must look to three principal markets in the future: domestic consumption of fuels; mainland sales of refined products; and sales to petrochemical producers on the Island. Puerto Rican petrochemical manufacture is discussed in a later section of this chapter. The first two markets, sales on the Island and on the mainland, are of course related. Exports to the mainland are especially important to the future economy of the Island, since they are a means of paying for imports. (We can probably assume safely that no other important export market for refined products is likely to be accessible to Puerto Rican refiners.)

Foreign refineries can supply U.S. mainland markets and even markets on the Island itself. Puerto Rican refiners cannot take for granted a protected market for "home" consumption; they must remain competitive. While even European refiners could reach Puerto Rican markets under some conditions, the most probable sources of competition in the supply of refined products for the U.S. mainland or Puerto Rico are in the Caribbean and in Mexico. Table 38 lists the rated refinery capacity in those areas at the end of 1977. (Some of these estimates overstate the capacity of the refineries for sustained production; the true capacity in Puerto Rico, for instance, is nearer 260 than 284 thousand barrels per day.) Many of the small refineries produce for home consumption only. Puerto Rico's major competition is from the Bahamas (for fuel oil),[1] Aruba-Curacao, Trinidad, Venezuela, and the Virgin Islands, and soon from Mexico.[2]

The mainland United States will continue to import refined products for the indefinite future; additions to refinery capacity cannot be

Table 38 Rated refining capacity in the Caribbean Basin and Mexico, January 1, 1978

Country	Refining capacity (thousands of barrels per day)
Bahamas	500.0
Barbados	3.0
Colombia	165.0
Costa Rica	10.0
Dominican Republic	46.5
El Salvador	16.5
Martinique	11.9
Guatemala	14.0
Honduras	14.0
Jamaica	32.6
Mexico	1,243.5
Netherlands Antilles	842.0
Nicaragua	14.9
Panama	100.0
Puerto Rico	284.0
Trinidad-Tobago	461.0
Venezuela	1,445.5
Virgin Islands	782.0
Total	5,986.4

Source: Petroleum Publishers. 1978. International Petroleum Encyclopedia. Tulsa, Okla.

large enough to eliminate imports of products. The eastern seaboard of the United States--more precisely Petroleum Administration for Defense District I (PAD I)--will import a large proportion of the products it consumes, for several decades or as long as it can obtain supplies elsewhere. Refiners in the rest of the United States will not be able to supply all of that demand.[3] Products will come from offshore, chiefly from refineries in the Caribbean and Mexico.

There is no reason Puerto Rican refineries should not help supply that demand if they can maintain processing efficiencies comparable to those of their Caribbean competition and if they can ship to the mainland at equivalent transport costs. Their crude oil costs will be the world prices in export markets, equivalent to those of competing foreign refineries, and their processing efficiencies should be at least as great. Mainland demand can easily absorb their exports. Their mainland markets may even be slightly protected if the United States should maintain a differential tariff on products refined in foreign countries.[4]

One encouraging factor in the future of CORCO is the excellent adaptation of its refining complex to the production of unleaded gasoline. CORCO is one of the largest U.S. producers of aromatics, some of which (xylene, toluene) are regularly used in the production of unleaded gasoline. This product is already in short supply on the mainland; demand for it is bound to grow under environmental protection rules already in effect. A favorable market for CORCO should result, and price differentials for unleaded gasoline should be even more favorable if price controls are removed from the U.S. market.

Crude Oil Supply

Both Puerto Rico and the mainland will be affected by a multitude of factors and events relating to energy during the next few years; we cannot predict them all. One of the most troublesome is the supply of crude oil. Current events again have thrown into high relief the dangerous dependence of the United States on foreign oil supplies. Puerto Rico participates in that dependence, and in the dangers. Without saying more about the U.S. energy predicament, we point out that Puerto Rico's requirements for crude oil at current levels of operation are only 3 to 4 percent of the crude imported by the United States. (See Table 39 for relevant magnitudes as of 1977.)

In an equilibrium market, with supply and demand in balance, Puerto Rico would be able to secure its small share by routine purchases on world markets. But a violently disequilibrated market, with spot shortages and rapidly changing prices, complicated by price controls and supplier allocations, presents a different picture.

Table 39 Crude oil and refined products: imports and consumption, Puerto Rico and the U.S. mainland, 1977

	Thousands of barrels per day
Crude oil imports	
To Puerto Rico[a]	213
To U.S. mainland	6,565
Shipments of refined products to U.S. mainland	
From Puerto Rico	96
From all suppliers	2,145
Consumption of refined products	
Puerto Rico[b]	251
U.S. mainland	18,450
Output of refined products	
Puerto Rico	231
U.S. mainland	16,305

[a]Does not include imports of naphtha into Puerto Rico (116 thousand barrels per day in 1977).

[b]Including 116 thousand barrels per day of imported naphtha.

Source: British Petroleum Company Limited. 1977. BP Statistical Review of the World Oil Industry. London; The Pace Company Consultants and Engineers, Inc. January 1979. Refining and Petrochemicals in Puerto Rico. Report prepared for the Puerto Rican Refining/Petrochemical Group. Houston, Tex.

As long as shortages persist, Island refiners like CORCO may have to rely on government allocations, at least in part. In the long run, they may find it useful to join buyers' consortia or enter into long-term contracts with national companies in oil-producing countries to protect their crude supplies from preemption by vertically integrated supplier-distributors. Advice on these matters is doubtless unnecessary.

Following its bankruptcy, CORCO was forced to rely on traders and brokers who were essentially buying oil in world spot markets. Since the spot price of crude oil has soared above the posted price in recent months, that reliance has been a burden, even though product prices have increased enough to enable CORCO to turn a profit on its refining activities. CORCO has announced its intention to find more long-term contractual sources of supply. One possibility is the proposed arrangement with Arabian Seaoil Corporation, which would invest $70 million in CORCO, arrange additional financing, arrange for the supply of 100 thousand barrels per day of oil from Eastern Hemisphere sources at competitive prices under long-term commitments, and enable CORCO to emerge from bankruptcy.[5]

The traditional major source of crude oil for Puerto Rico has been Venezuela. The fraction supplied by Venezuela (over 90 percent in 1973) began to fall sharply several years ago, as Puerto Rican refiners and their intermediaries turned to Eastern Hemisphere sources. Both Venezuelan production and exports fell concurrently, apparently as a direct consequence of a decline in production capacity. In 1976, Puerto Rico imported about 100 thousand barrels per day from Venezuela, down from nearly 200 thousand in 1973.[6]

Venezuelan exports had peaked in 1970 at 3,470 thousand barrels per day. By 1975 they fell to 2,050 thousand and by 1979 were down to 1,900 thousand. Direct exports to the United States have remained at a fairly constant one-third of Venezuelan exports, but the absolute amount has declined considerably since 1970. In 1976, direct Venezuelan exports to the United States (excluding Puerto Rico) were 708 thousand barrel per day--crude oil, 262 thousand; heavy fuel oil, 435 thousand; and other products, 11 thousand.[7] (In 1973, crude exports to the United States had been 496 thousand barrels per day.) Puerto Rico could absorb over half of the total Venezuelan crude exports to the United States (including the Island) if Venezuela were its only large source and if Venezuelan export levels remained near their 1976-77 levels.

If Venezuelan production expands in the future, the increment will probably consist largely of heavier crudes with high sulfur contents. If Puerto Rican refineries come to rely on those crudes for a large proportion of their inputs, they will have to reengineer some refining facilities and add specialized storage and handling equipment, necessitating considerable capital outlays. CORCO could not handle crude with a very high sulfur content on the Island. It is already near the limit of tolerance of environmental rules.

Venezuela would probably have to build desulfurization plants to remove sulfur before exporting the oil--something it would probably find in its interest regardless of the oil's destination. These future developments, of course, are highly speculative.

Almost all countries that export crude oil are promoting downstream integration into refining and petrochemical manufacture. In the future, many may refuse to export crude at all, or may export crude only to countries willing to absorb growing quotas of refined products. While Puerto Rico's use of total United States crude imports is small (about 3 percent), it could possibly suffer from such a squeeze on crude oil supply. It cannot look to the United States mainland for crude supplies. Caribbean supply would not be enough to feed Caribbean refining capacity if the latter relied solely on oil from the Caribbean Basin. (Compare Table 40 with Table 38.) Mexican oil is not likely to be refined in the Caribbean in large quantities. The crude that Mexico is willing to export to the United States will probably be refined in mainland plants on the Gulf Coast or in PAD I.

Table 40 Crude oil production in the Caribbean Basin and Mexico, 1977

Country	Production (thousands of barrels per day)
Barbados	0.3
Colombia	140.0
Mexico	990.0
Trinidad-Tobago	230.0
Venezuela	2,280.0
Total	3,640.3[a]

[a]In 1973 the total for these countries was 4,193 thousand barrels per day. Production thus has declined by 13.2 percent.

Source: Donald Baer. 1978. Petroleum Supply, Demand, and Interdependence in the Caribbean Basin. Caribbean Basin Economic Survey 4(5)(September-October):1-18.

Puerto Rico will have to import much of its crude oil from the Eastern Hemisphere for the next decade at least.[8] It could find itself in a competitive scramble with mainland United States refineries for a diminishing volume of crude imports in the long run. (It shares that predicament with oil-importing entities everywhere in the world, of course.)

The recent announcement of a United States policy to limit total imports to 8,200 thousand barrels per day for 1980 and 1981 (assuming that much supply to be available), and to lower targets thereafter, may portend additional problems for Puerto Rican refineries. There is no suggestion that Puerto Rico would be exempt from an import quota. Such a ceiling would probably not be binding on the United States during 1980 and 1981, but after that an import quota could produce the same results as in the 1960's--domestic prices higher than world prices, and the need for a rationing system for import rights. An auction system would have different, and probably more threatening, implications for Puerto Rican refiners than would a 1960's--style system of allocating rights in proportion to capacity or historic import dependence. Again, we can only speculate on future development of policy, but we think it highly likely that any import-control program will include some safeguards for smaller, unintegrated, import-dependent refineries like CORCO.

Transportation Costs

Without the Jones Act, the costs of transporting refined products from Puerto Rico to the eastern seaboard refineries of PAD I would be approximately the same as those of the principal competing refineries. With it, Puerto Rican costs of transportation exceeded those of competitors (including the Virgin Island refineries, which are not subject to Jones Act restrictions) by about 45 to 50 cents per barrel as of 1978.[9] This differential was largely offset, until recently, by the differential tariff on refined products, described earlier. Even a small transportation cost disadvantage in reaching East Coast ports could be decisive in an equilibrium market, and certainly depresses the earnings of Puerto Rican refineries when they sell on the mainland.

The best way to solve that problem would be to exempt transportation of oil products refined in Puerto Rico from the Jones Act. (This exemption need not include petrochemicals, which are not subject to equivalent disadvantages from the Act.) Maintaining a large enough differential tariff on refined products, with Puerto Rican refineries exempt, might serve as an alternative, but future effects of import quotas and other circumstances on tariff differentials cannot easily be foreseen. Exemption of product shipments would be more permanent. If neither of these options is available, then as a last resort the Puerto Rican government should apply to Congress for cash subsidy to exports of refined petroleum products to the mainland, equal to the Jones Act disadvantage relative to major Caribbean competitors--a subsidy to offset another subsidy.

Import Quotas, Entitlements, and Price Controls

The original advantage for Puerto Rican refineries--the ability to buy crude at low world prices and sell products in the higher priced United States mainland markets--was reinforced during the 1960's by the Mandatory Oil Imports Program (MOIP). The quotas fixed by that program generated a pool of money (from the difference between the world price of crude and the internal United States price) that was distributed to refiners, in the form of "rights" to import, according to a complex and evolving scheme. Special exemptions for Puerto Rico created flows of funds--subsidies, in a word--more than sufficient to offset the transportation cost differential and other disadvantages and to encourage rapid development of the refining complex on the Island. Those subsidies ended in 1973, when the world price of crude oil rose above United States levels and MOIP quotas were phased out.

The shock of 1973-74 has led to the present predicament. In looking for solutions, we should not merely yearn for the *status quo ante*. Sources in Puerto Rico sometimes assume that the United States government has a moral obligation to restore the cost-price relationships that existed under MOIP, because investments were made in refining (and petrochemicals) on the presumption that the subventions would last indefinitely, while the government used the import quota exemption as an inducement to develop the Island economically. They have suggested that the entitlements program, designed to equalize the blended cost of low-priced "old" oil and higher-priced "new" and imported oil among United States refiners, is a continuation of the MOIP and should be used for the same purpose.[10]

Without commenting on the expectations that might have been formed in the 1960's, we believe it would be a mistake to use the entitlements program now to create an artificial crude-oil advantage for Puerto Rican refineries like the one that existed under MOIP. What is essential for refining is cost parity with Puerto Rico's competitors. Island refineries should be able to achieve the technological efficiency of refineries on the mainland and elsewhere in the Gulf/Caribbean region.[11] Their labor costs should not be a disadvantage. Fuel costs on the mainland are rapidly rising to world levels. The transportation cost penalty of the Jones Act, as suggested above, might warrant a small subsidy, differential products tariff, or other compensation for Puerto Rico, but that should not be tied to the entitlements program.

As long as price controls on old oil continue on the mainland, and prices of refined products are tied to the blended costs of high- and low-cost crude, the entitlements program will be needed to promote equity among refiners. The Puerto Rican refineries will participate in it. The program aims at cost parity, not at cost advantage. But parity in the future is much more likely to result from oil price decontrol. Within a few years, price controls in the United States are likely to be phased out, and in any event the supply of "cheap" old oil will be rapidly depleted. The prices of oil in the United States by the middle 1980's should be on a "world" basis, and all refineries in the Gulf-Caribbean area will probably have parity in feedstock prices.

In a decontrolled market, the relevant competition for the Puerto Rican refineries will be foreign offshore refineries, not mainland United States refineries, though the latter will probably not differ much in costs from the foreign suppliers. The low transportation cost of domestically produced crude for mainland refineries is irrelevant as a competitive factor if crude prices on the mainland are determined by the landed costs of foreign crude. As long as the eastern seaboard of the United States (PAD I) must import foreign-refined products in any volume, the prices of that incremental supply (in an uncontrolled market-price system) will be the prices that Puerto Rican refineries must meet. In 1977, a large part of United States product imports went to PAD I. Puerto Rico should be able to supply up to the 100,000 barrels per day that it has recently been exporting to the eastern seaboard. It should be able to achieve cost parity for mainland sales of refined oil products if the Jones Act disadvantage is neutralized by one means or another.

On the other hand, Puerto Rico will not be an especially favored source of supply in the future. It has no cost advantages that would warrant expansion of refining on the Island for the purpose of enlarging exports to the mainland.[12] We expect that any growth in demand for refined products on the Island will absorb some of the present export flow, and possibly use more of the existing capacity, but it will not support major increases in refining capacity.

Petrochemicals

The problems associated with petrochemicals in Puerto Rico are primarily problems of economic development strategy, which is not the charge of this committee. They are only secondarily problems of "energy." But, since petrochemicals are tied into the petroleum production stream and CORCO has been involved with petrochemicals as well as refining, we offer the following observations on the matter.

Much depends on the answers to several questions:

- Can Puerto Rican petrochemical manufacturers achieve cost parity with mainland manufacturers with respect to the costs of feedstocks, transportation, power, and other factors?

- Can the Island companies attain a more "balanced" structure?

- What are future market conditions likely to be for Puerto Rican petrochemical plants?

Feedstock Costs

Puerto Rican petrochemical plants use naphtha as their principal feedstock. Part is produced in Island refineries, but most is imported. Competitors on the mainland use naphtha in some plants, but in the past most mainland olefin plants have used liquefied petroleum gases (LPG) derived from natural gas. About 75 percent of the ethylene produced in the United States is made from LPG. However, most new ethylene capacity being constructed on the mainland is designed to use naphtha and gas oil derived from petroleum.

Under price controls, domestically produced naphtha has been cheaper than imported naphtha. (It is difficult to say how much, since most mainland naphtha moves within integrated company structures and has only a nominal price for accounting purposes.) It is one of the aims of the entitlements program to equalize the cost of crude inputs among refiners, but it does not necessarily to the same for the feedstocks of petrochemical producers. Puerto Rican producers have recently been buying naphtha on the spot market, where prices have escalated well above the transfer prices for naphtha available to integrated mainland producers. The entitlements program limits the value of a naphtha entitlement (relative to the imputed mainland naphtha cost) to no more than the value of a crude entitlement.[13] The actual cost difference has exceeded the value of the entitlement in recent months by upwards of $5 per barrel of naphtha. Prices of some petrochemicals have also escalated, but others (notably ethylene) have suffered a cost-price squeeze.

When and if the buying panic recedes, the spot price of naphtha should move down toward contract prices, but the Island producers can protect themselves better with longer term buying contracts. The best remedy for the problem of relative naphtha costs in the long run is, of course, prospective decontrol of oil prices and elimination of entitlements. If decontrol proceeds as expected, the long-run incremental cost of naphtha on the mainland will approximate the world price paid by European chemical producers and Puerto Rico.

The entitlements program has little bearing on relative feedstock costs as between naphtha and LPG. The rise in world oil prices has rapidly pushed the price of naphtha above LPG costs. The latter are rising too, but have lagged behind naphtha prices. We can only guess at the future course of both naphtha and LPG prices, and their relative use on the mainland, to appraise the possibility of feedstock cost parity for Puerto Rico.

The following observations on feedstock prices are pertinent:

- Light feedstocks (ethane, propane, etc.), which have historically been preferred for ethylene manufacture in the United States, are going to continue to increase in price. In the case of domestic feedstocks, the cause will be the increasing price of natural gas, raising the value of leaving the materials in gas. In the case of imported LPG, it is because the major supplies are in the hands of OPEC countries, who will not sell at a discount.

- The move in the United States to build ethylene plants using naphtha or gas oils as feedstocks will continue, and by 1985 more than half of the nation's ethylene will be produced from these materials.

- Crude oil in the United States will continue to rise in price and will approach world price levels, reaching them for practical purposes by 1985 or before. The United States will no longer have any substantial advantage in cost of feedstocks to refineries.

- The United States will continue to import large quantities of foreign crude oil and will import increasing quantities of refined products, including possibly ethylene feedstocks, as rising United States demand exceeds domestic refinery capacity. These imports, however, may eventually be subjected to quota limitations and to allocation by the government.

- The cost of refinery construction in the United States will likely continue to be higher than in those countries that are probable sources of naphtha for Puerto Rico.

- The United States is losing its cost advantage for ethylene feedstocks, and in terms of economic values rather than nominal accounting prices, Puerto Rico should be at no competitive disadvantage by comparison with the mainland in this regard in the future. This says nothing, of course, about other sources of competitive advantage or disadvantage.

Transportation Costs

Will Puerto Rican petrochemical plants suffer from an adverse differential in transportation costs in the future?

The landed prices of petroleum or naphtha feedstocks in Puerto Rico in the long run should be the same as or less than on the United States Gulf Coast, which is the site of most of the competitive plants producing basic petrochemicals. The fact that mainland plants can buy domestically produced United States oil or naphtha will be irrelevant if prices are not controlled; the price of the marginal (imported) barrel will determine the price for all. While prices are still controlled, presumably the entitlements program will at least partially compensate for differences.

Most petrochemical products will move to markets in the eastern United States. The Jones Act does not seem to impose an appreciable cost disadvantage on petrochemicals, and derivatives produced on the Gulf Coast also have to move to these markets by ship (also subject to Jones Act restrictions) or by higher cost modes of transport. In the second place, foreign producers such as those in the Caribbean will have to sell in the United States across a tariff barrier which at present seems more than ample to compensate for the provisions of the Jones Act.[15] (We recognize that the cost of transporting ethylene by sea is high, but that is a question of what products to ship, not of Jones Act costs.)

Salt, on the other hand, is prohibitively expensive to ship to Puerto Rico (by comparison with its cost on the Gulf Coast). Salt was a necessary input to the chloralkali plant of PPG, now closed and being dismantled. There is no evident way of attaining cost parity for this input.

There remains the cost of shipping equipment and some minor inputs from the mainland to Puerto Rico. These costs are largely offset by lower construction labor costs on the Island.[16] In other respects, transportation does not seem to present a major cost disadvantage to Puerto Rican petrochemical producers.

Power and Other Factor Costs

Power costs are a significant factor in production of some petrochemicals. At present, electric power costs on Puerto Rico are substantially above those on the United States Gulf Coast, averaging perhaps twice as much to petrochemical producers.[17] However, as pointed out in the report prepared for the government by the Pace Company in early 1979 (known as the "Pace Report"),6 fuel costs on the Island are current costs while those on the mainland are lagging. As fuel contracts expire, higher costs will overtake the Gulf Coast plants. (Fuel adjustment costs per kilowatt-hour for systems using natural gas on a current-price basis, such as San Antonio, are already equivalent to those in Puerto Rico last year.) We may expect convergence of fuel costs in the future, and a narrowing of the gap in average power costs.

Chapter 5 notes that further increases in electric power costs on the Island, over and above higher fuel input costs, are inevitable; the same can be said about mainland power costs. Chapter 5 also recommends measures to hold cost increases down by optimizing the Island system.

The Pace Report[6] predicts somewhat lower labor costs for Puerto Rico than for mainland plants. Wage rates in the refining and petrochemical industries on Puerto Rico are about 30 percent below mainland rates. However, these are not labor-intensive industries; labor costs range from 2 to 7 percent of total costs.[18] Tax costs reflect government promotion policy, and can be kept at parity or less for Puerto Rican plants by its action.

Structure and Downstream Integration

The petrochemical industry is characterized by a complex set of linkages and interdependences. Figures 7 and 8 show how these stages and interrelationships would be arranged in Puerto Rico if the industrial complex were operating as planned.

Unfortunately, not only is much of the existing system shut down, but the structure of the petrochemical industry on the Island was in fact never developed to an optimum or balanced system. One major anomaly has already been mentioned; there are not enough users in Puerto Rico for all the ethylene that Island facilities were designed to produce, and the surplus cannot be shipped economically to off-Island users. The downstream integration originally planned has not materialized. Another anomaly is the currently uneconomical basis for the chloralkali plant of PPG Industries Caribe. Its closing and subsequent dismantlement has further indirectly curtailed the outlets for ethylene by depriving the vinyl chloride processes downstream of some essential inputs.[19]

The difficulties of Puerto Rico Olefins (PRO) seem to have been due in part to plans that were not consistent with market opportunities and to unanticipated changes such as abandonment of plans to manufacture styrene, as well as to events in energy markets.

The viability of the chloralkali and vinyl chloride operations of PPG depended on the very low cost of electric power that was available before 1973 under Public Law 82. Power costs were dominant elements for this facility; some 100 megawatts of electric power capacity, which would otherwise have been absorbed by it, will be available for other kinds of industrial development. In that event, Rico Chemicals might be able to continue operations using imported vinyl chloride, or ethylene dichloride to be cracked to vinyl chloride on the Island. But permanent closure of the PPG Industries Caribe chloralkali facility would mean that unused ethylene capacity in the PRO cracking plant could be as much as 450 million pounds annually.

Polyethylene and styrene production appear to be the best technical possibilities for downstream expansion to absorb ethylene, but the lead times are long and the market opportunities do not look especially favorable. Both CORCO and PPG Industries Caribe have announced their proference for disposing of the closed-down ethylene unit.[20] Any prospective buyer would need to establish or to attract at least one major additional ethylene user to secure the long-term position of the PRO plant and thereby eliminate the major factor responsible for its current shutdown. This would require investment that could not become operational for some considerable time. However, it is conveivable that the PRO plant could be operated on an interim basis, supplying feedstocks to the existing ethylene-consuming units in the South Coast petrochemical complex.

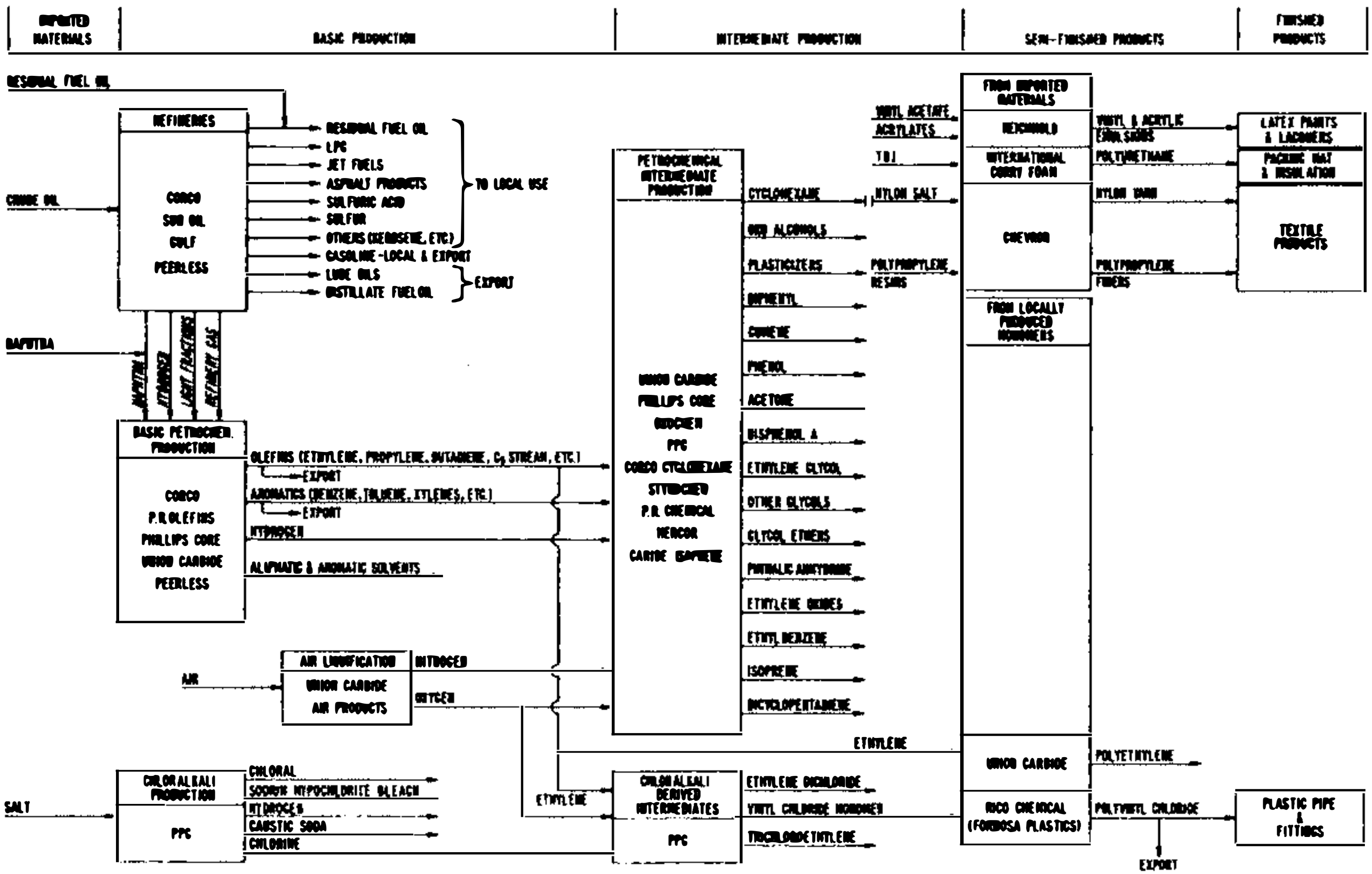


Figure 8 Puerto Rico refining and petrochemical industry: imported materials to finished products (The Pace Company Consultants and Engineers, Inc. January 1979. Refining and Petrochemicals in Puerto Rico. Report prepared for the Puerto Rico Refining/ Petrochemical Group. Houston, Tex. p. 27.)

Although some opportunities do exist for further downstream development on the Island, especially in plastics fabrication,[21] the Puerto Rican experience in the development of such activiites based on primary petrochemical production has been disappointing. However, this experience is by no means unique. Planning agencies in many countries have discovered that the existence of technical linkages is no guarantee that apparently logical developments will take place.

There are several reasons for this. The nature of petrochemical products changes fundamentally as they pass through the different stages of production. Technical factors that encourage the agglomeration of basic manufacturing processes are less relevant in the later stages. Generally speaking, products become more elaborate and less uniform with each stage of the manufacturing process. Cooperation with individual consumers is an important factor affecting the volume and specification of plant production, and location relative to major customers becomes more significant than proximity to source raw material.

This locational shift is reinforced by the fact that solid process materials, which are relatively easy to transport, tend to replace the less stable liquids and gases that draw the earlier stages of production together. The different techniques employed in the manufacture and manipulation of plastic materials ensure that this stage in the conversion process is generally regarded as the responsibility of the plastics industry, while the initial operations fall within the scope of the petrochemical industry. Similar distinctions apply to the production of petroleum-derived synthetic fibers. The manufacture of basic intermediates is performed in petrochemical complexes, but their conversion into fibers is carried out by the textile industry, and the location of spinning facilities is affected by an entirely different set of factors from those that affect the earlier stages.

Alternative paths of economic development really do not have a predictable relation to energy alternatives. If other industries replace petrochemical-based activities in the development strategy of the Island, the effect on energy requirements will be problematical until the natures of those industries are known. All that can be said is that the use of petroleum products as fuel or feedstocks is not likely to increase as other industries replace petrochemical development.

Market Conditions

The principal market for petrochemicals produced in Puerto Rico is the mainland United States. In that market Puerto Rican petrochemicals enjoy the protection of a moderate tariff barrier. Imports of petrochemicals into the United States are not negligible--about 3 to 4 percent of the aggregate supply is imported--and some categories are duty-free. Nevertheless, the main competition for Puerto Rican plants is located on the Gulf Coast and in the eastern states.

As noted earlier, markets for aromatics produced on the Island appear very favorable, including their use by CORCO in unleaded gasoline supplied to the mainland. For ethylene and its principal derivatives, market conditions for the next few years in the United States do not seem promising because of low profit margins and excess capacity. This factor contributes to the negative assessment for additional capacity in the ethylene stream in Puerto Rico.

Puerto Rican production of the finished and fabricated products whose production is still possible on the Island would doubtless be only a small proportion of United States output, and they would not in themselves have a strong impact on mainland markets.

The world market for petrochemicals and derivatives appears uninviting. In 1978, United States producers exported about 12 percent of aggregate petrochemical production (by value), but this export record has been based on the historically low feedstock costs of LPG-based plants. Most sources agree that this advantage is eroding very rapidly, and that export markets will be less promising for United States producers in the future.[22]

There is already considerable excess capacity in the world, and it is expected to grow over the next decade or so. Many less-developed oil-exporting countries are trying to create downstream industries linked to petroleum, and petrochemicals beckon as a natural avenue for development. Some other countries newly entering petrochemical production have arranged to pay back some of the external investment costs with the petrochemicals to be produced.[23] The general expansion of capacity is not closely regulated by profit expectations. Under the circumstances, European and Japanese petrochemical producers, with prospective excess capacity, can be expected to be particularly agressive competitors in any third markets that Puerto Rican manufacturers might hope to reach. Even the mainland United States markets may not be immune from substantial foreign competition.

SUMMARY AND CONCLUSIONS

Refining

The refining operations on the Island, including CORCO, appear to be viable. They should be able to supply both local and mainland markets profitably, if the following two problems can be surmounted:

- Island refiners should seek some means of overcoming the (relatively small) transportation cost disadvantage resulting from the Jones Act, such as an exemption for transportation of refined petroleum products to the mainland.

• Island refiners may have difficulty securing adequate supplies of crude oil. This problem also afflicts mainland refiners and those in other oil-importing countries. A more reliable procurement system appears to be highly desirable.

Petrochemicals

The competitive position of the Puerto Rico petrochemical industry with respect to mainland manufacturers should improve as the latter become more dependent on liquid feedstocks derived from imported and deregulated domestic crude. Power and transport are also unlikely to create significant cost penalties. Despite these favorable general conditions, the prospects for petrochemicals differ according to the specific circumstances of the principal types of product:

• Aromatics production has been and seems likely to remain a profitable operation with the prospect of some modest expansion in line with demand.

• Chloralkali production depended upon the artificial circumstances created by the availability of subsidized electricity rates. The uneconomic nature of the operation is emphasized by the fact that this plant is being dismantled. Chloralkali production is unlikely to become a viable proposition on Puerto Rico under any forseeable circumstances.

• The olefins (especially ethylene) and their immediate derivatives raise the most important issues. The shutdown PRO facility is the critical problem. This unit could be operated profitably if its potential output of ethylene were matched by a corresponding demand in downstream units. Existing units do not have even the nominal capacity to provide this demand, and the closure of the chloralkali plant may further reduce ethylene consuming capacity by threatening the viability of vinyl chloride production. Thus, reopening the PRO facility will require investment in at least one major additional ethylene-consuming facility.

• Major new investments in such downstream operations as plastics fabrication and synthetic fibres are unlikely. Such activities tend to depend on the proximity of a market, rather than that of raw materials. It would certainly be overoptimistic to think in terms of substantial developments aimed at mainland markets. It is more realistic to anticipate minor expansion geared to growth in demand on the Island.

Oil Refining, Petrochemicals, and Energy Demand

In projections of the future demand for energy attributable to refining and petrochemicals manufacture, the following assumptions appear to be prudent:

- Refinery production will grow modestly to supply additional demand for refined products in Puerto Rico.

- Aromatics production will grow at the same rate as total United States demand for these products.

- The PPG Industries Caribe chloralkali plant will not be reopened.

- Efforts will be made to resume operations of the PRO ethylene cracker, as a vital element in further balanced development of the petrochemical complex. Hence, enough electric power generation capacity should be "reserved" to support full operation of this facility until it becomes clear whether it can reopen. Any other significant change in energy demand from the petrochemical sector should become evident with enough lead time for appropriate action.

NOTES

1. In 1978, Grand Bahama Petroleum Corporation, one of the two companies operating the principal refinery in the Bahamas, declared bankruptcy.

2. In 1978, Mexican refining capacity was still used predominantly for home consumption. Mexico produced about 1,400,000 barrels per day of crude oil and consumed about 1,000,000 barrels per day. Exports of crude oil to the U.S. mainland in June 1978 averaged 242,000 barrels per day. However, PEMEX has announced plans to export about 1,100,000 barrels per day by 1982, 700,000 as refined products and 400,000 as crude. Not all of these exports are destined for the mainland--perhaps no more than half. (OPEC Bears Brunt of U.S. Oil Import Slash. 1978. Petroleum Intelligence Weekly 17(46) (November 13):11; Hugh Sandeman. 1978. PEMEX Comes Out of Its Shell. Fortune 97(7) (April):45-48.)

3. In 1976, PAD I (U.S. eastern seaboard) consumed about 3,190,000 barrels per day of products refined elsewhere in the United States, mostly on the Gulf Coast, plus 1,517,000 barrels per day refined in PAD I itself, plus 1,694,000 barrels per day of products imported from offshore refineries. (Estimates are from E. Victor Niemeyer and James W. McKie. 1979. U.S. Oil Geography in 1990: Scenarios and Implications for Economic Policy. Policy Study No. 5. Center for Energy Studies. Austin: University of Texas.)

4. Imports to the mainland from other Caribbean points, including the Virgin Islands, or from any other foreign refineries, but not from Puerto Rico, would be subject to these duties. Puerto Rico refiners would have to pay the import duties on crude oil and naphtha. In 1978 the tariff was 5.25 cents per barrel on heavy crude oil (below 25^{o} API) and on residual fuel oil; it was 10.5 cents per barrel on lighter crudes and distillate fuel oil. The tariff was 52.5 cents per barrel on motor fuel products. But there were also "license fees" on some imports—21 cents per barrel on crude oil and 63 cents on refined products other than residual fuel oil, including naphtha--against which tariff payments could be credited, on a dollar-for-dollar basis. The net result of these complicated provisions would be an advantage to Puerto Rican refiners over other Caribbean refiners of over 40 cents on shipments of products to the mainland, assuming that Puerto Rican refiners paid higher prices for imported crude oil, due to U.S. tariffs and fees. (Imports from Venezuela into Puerto Rico were exempt from license fees.) These fees and duties on U.S. imports were suspended by Presidential order early in 1979.

4. (Continued)
The suspension will be reviewed periodically, but no permanent substitute for the withdrawn tariff on products has yet been proposed.

5. Commonwealth Oil Refining Company, Inc. June 1979. Report to Shareholders. San Antonio, Texas.

6. The Pace Company Consultants and Engineers, Inc. January 1979. Refining and Petrochemicals in Puerto Rico. Report prepared for the Puerto Rican Refining/Petroleum Group. Houston, Texas.

7. Comptroller's Department, LAGOVEN, S.A. August 1977. Data on Petroleum and Economy of Venezuela, 1976. p. 25. In 1977 Venezuela exported 307,000 barrels of crude oil per day to the United States mainland, plus 421,000 barrels per day of refined products. In addition, 100,000 barrels of crude oil per day were exported to Puerto Rico. A substantial volume of Venezuelan oil (probably more than 500,000 barrels per day in 1976) was refined in the Netherlands West Indies, of which about 40 percent was shipped to the U.S. mainland. Refineries in Venezuela and Netherlands West Indies could absorb all of Venezuelan crude oil output.

8. At present about half of its crude oil comes from Venezuela and other sources in the Caribbean, and most of the remainder from Nigeria and North Africa. Naphtha is purchased in the Caribbean and the Bahamas and from European refineries.

9. Based on estimates in Pace Company, Refining and Petrochemicals (note 6). p. 40.

10. "In the same sense that the Mandatory Oil Imports Program (MOIP) in the 1960s served as a vehicle to provide extra benefits to certain segments of the oil industry through the grant of access to low-cost foreign oil, the Entitlements Program became the vehicle in the latter part of the 1970s to confer similar benefits through the grant of access to low-cost domestic oil.... However, the Entitlements Program has failed to reinstate the previous feedstock cost advantages enjoyed under the MOIP which were necessary to allow Puerto Rican firms to compete with mainland firms and to provide incentives for the economic development of Puerto Rico." (Government of Puerto Rico. January 31, 1979. Comments before the Office of Hearings and Appeals, U.S. Department of Energy, Washington, D.C. pp. 11-12, 14.) It is true that the Federal government held out special allocations and exemptions under MOIP as inducements to those under Operation Bootstrap.

11. "The lower crude oil costs which CORCO enjoyed during the early 1970s relative to its U.S. competition served to mask higher operating costs and inefficiencies." (Commonwealth Reorganization Co., Inc. December 1978. First Phase Report to Commonwealth Oil Refining Company, Inc., the United States District Court for the Western District of Texas, and the Creditors' Committee. San Antonio, Texas. p. 13.)

    The report goes on to express confidence that these inefficiencies can be eliminated; it does not ask for a subsidy to perpetuate them. This committee cannot offer useful suggestions to CRC in its efforts to reorganize CORCO; those who are guiding the reorganization have the facts, the expertise, and a strong motivation to make it succeed.

12. The Commonwealth Reorganization Company has suggested that "an idle Styrochem unit can be converted into a crude unit capable of processing 120,000 barrels per day at a cost of approximately $20 million." (First Phase Report (note 11), p. 3.) This unit would replace some obsolescent capacity, which would be retired. Although this and other possible changes might increase capacity somewhat, their primary purpose would be improvement of efficiency, altering the product mix in favor of higher value products, and reducing inputs of purchased naphtha. (The Styrochem plant is not shown on Figure 7; it has been shut down since 1976. It was designed to recover ethylbenzene, an intermediate in the production of styrene and polystyrene, which were never developed on the Island.)

13. On May 16, 1979, the Office of Hearings and Appeals of the U.S. Department of Energy proposed to double the number of entitlements that the Island petrochemical producers received for each barrel of imported naphtha used, for a six-month period. After additional consideration it decided to reverse its findings, on the ground that no undue hardship or emergency had resulted from naphtha price increases. It also observed that the Naphtha Entitlements Program was not designed to equalize feedstock costs for Puerto Rican petrochemical producers. (U.S. Department of Energy. August 15, 1979. Decision and Order, Application for Exception. Office of Hearings and Appeals. Washington, D.C. Case Numbers DEE-2245, 2317, 3148.)

14. Based on Robert S. Spencer and Gerald L. Decker. 1979. Petrochemical Markets and Feestocks. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

15. After the "Tokyo Round" of 1979, most duties on petrochemical products were in the range of 5 to 12.5 percent ad valorem, although some were as low as 3 percent and some important products (benzene and cumene, for example), were duty-free. For ethylene oxide the duty was 9 percent, for propylene oxide it was 12 percent, and for polyvinyl chloride resins it was 10.1 percent.

16. Arthur D. Little, Inc. October 1977. Competitive Cost Position of the Puerto Rican Petrochemical Industry in 1977. Report to the Puerto Rican Petrochemical Group. Cambridge, Mass. p. 72.

17. Pace Company, Refining and Petrochemicals (note 6), p. 55.

18. Pace Company, Refining and Petrochemicals (note 6), p. 61-62.

19. The following paragraphs are based largely on Keith Chapman. 1979. The Structure of the Petrochemical Industry in Puerto Rico. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

20. "...PRO, Oxochem, and CIC [Caribe Isoprene Corp.] do not offer near-term profit opportunity, and are not compatible with CORCO's resources or business objectives. This report therefore assumes the writeoff of these facilities in the aggregate amount of $82 million in 1978." (Commonwealth Reorganization, First Phase Report (note 11), p. 52.) "PPG has indicated that it is making every effort to sell the PRO facility and that it does not contemplate reopening the facility itself." (U.S. Department of Energy, Decision and Order (note 13), p. 30.)

21. "...Encouragement of the construction of downstream petrochemical facilities must be given high priority...." (U.S. Department of Energy, Decision and Order (note 13), p. 22-23). The U.S. Department of Energy granted additional entitlements conditioned on dollar-for-dollar investment in such facilities. It is not clear that a program like this--essentially short run and limited in scope--could have an appreciable effect on downstream development.

22. See, for example, Harry F. Pfann. July 1979. Petrochemicals: The Economic Significance in the Domestic Economy. Draft. Washington, D.C.: U.S. Department of Commerce.

23. Cf. Organization for Economic Co-operation and Development. 1979. The Petrochemical Industry: Trends in Production and Investment to 1985. Paris. p. 12-17. Some oil-producing countries can take advantage of large supplies of low cost LPG as feedstocks.

5 THE ELECTRIC POWER SYSTEM

The Puerto Rico Electric Power Authority (PREPA), until recently known as the Puerto Rico Water Resources Authority, operates the largest and most sophisticated electricity supply system in the Caribbean. Its all-time peak load, recorded in September 1978, was 2,057 megawatts.

Until the mid-1970's, PREPA's main problem was increasing generating capacity quickly enough to meet the rapid growth in demand. Since the 1974 oil price rise, however, increased conservation efforts and sluggish economic growth have reduced energy demand. Electricity production in Puerto Rico grew at annual rates of about 14 percent over the four decades preceding the price rise; the growth rate since 1975 has averaged only 3 percent.

During the late 1960's and early 1970's, system planners, struggling to keep pace with growing power demand, constructed six large oil-fired generating units that almost doubled generating capacity. The large sizes of these 300 to 450 megawatt units make it difficult to maintain reliable service when one of them fails. With demand stagnant, the system will take at least a decade to grow large enough to accommodate these units comfortably.

The Authority faces another problem, no less troubling; its current financial position is such that it may be difficult to finance the next addition to generating capacity. PREPA's latest borrowings have evoked signs of wariness on the part of the bond market. To construct the next generating unit, the Authority will have to borrow perhaps $300 million each year for several years in the early 1980's; to do this at reasonable cost it will have to raise its revenues substantially, primarily by raising rates.

It is easy for outside experts to tender good advice; putting that advice into effect is infinitely more difficult. This committee can offer some recommendations after its survey of PREPA's situation, but correcting these problems will not be simple. The operational and financial problems of the system can be corrected only by conscientious and dedicated management and far-sighted action by the rate-setting authorities. This committee can only stress the urgency of the task.

IMPROVING SYSTEM RELIABILITY

The four largest units on the PREPA system have capacities of more than 400 megawatts each, and the large sizes of these units, in proportion to the typical system load, is a severe handicap to the system's reliability. An unexpected shutdown of any of the four, when the system is operating at loads between 1,500 and 2,000 megawatts, involves the loss of about 20 to 25 percent of total power generation. This is more than can be smoothly replaced by the available quick-response reserves, and the result is frequent interruptions in supply.

The system's basic problem in this situation is not planning future capacity additions (though these will be necessary in the coming decade), but managing the generating units now on line as effectively as possible given the difficult circumstances. PREPA is an Island system, unable to draw on neighbors for emergency power, and it has no seasonal demand valleys in which to schedule major maintenance. This committee's interim report recognized these unavoidable difficulties; each raises reserve capacity needs beyond those of systems not handicapped in these ways. However, the report pointed out that with a peak demand of about 2,000 megawatts and a total generating capacity of 4,200 megawatts, PREPA has a reserve margin of more than 100 percent, far greater than the 20 to 30 percent considered adequate on the mainland, and much larger even than the reserves of other isolated systems. (Table 41 is a summary of the operating characteristics of a few other island electrical systems.)

Even with the very high reserve margin PREPA is subject to frequent interruptions in service. In explaining this, the interim report pointed to the high forced outage rates of the large units, which were approximately double those of comparable mainland units in the years 1967-1976. The report recommended that "a concentrated effort should be made to improve the maintenance and availability of all steam-electrical generating facilities...(especially) the four large units at Aguirre and South Coast...."[1] It also recommended that more quick-response generating capacity be made available by operating the large units slightly below full capacity and refurbishing some of the fast-starting gas-turbine generating units, so that lost generating capacity could be more smoothly and rapidly replaced. (The report recognized PREPA's two-year program to improve availability and reduce maintenance time, and offered some general advice on scheduling and performing inspections and maintenance.)

Table 41 A comparison of isolated electrical generation systems

Attributes	Taiwan	Oahu, Hawaii	Luzon Philippines	South Korea	Puerto Rico
Service area					
Area (square miles)	13,885	608	54,595	38,031	3,435
Population (estimate)	14,000,000	720,000	25,000,000	37,000,000	3,300,000
Number of customers		205,260	3,000,000	4,940,000	914,466
Percent of households served	99.7	100	58	100	99.0
Energy					
Net total power generated (millions of megawatt-hours)	30.36	5.21	10.75	31.51	13.69
Sales to industry (percent)	75.5	51	42	71.0	41.5
Sales to commercial (percent)	3.9	18	26	14.8	29.2
Sales to residences (percent)	20.6	30	6	14.2	31.7
Peak					
Peak power (megawatts)	5,093	905	1,780	5,118	2,017
Reserve (percent peak power)	28	34	36	35	108
Annual load factor (percent)	68	69.2	72	70.3	77.4

System make-up					
Thermal (steam)(megawatts)	5,050	1,068	1,897	4,692	3,083
Nuclear (megawatts)	636	0	0	487	0
Hydroelectric (megawatts)	721	0	527	712	98
Combustion (megawatts)	100	141	5	925	1,007
Total (megawatts)	6,507	1,209	2,429	6,916	4,199
Largest unit (megawatts)					
Thermal	2 x 500	1 x 135	2 x 300		2 x 450
Nuclear	1 x 636			1 x 587	
Largest unit, percent of peak	12.4	14.9	17	11.5	22

Source: For Taiwan, Vaclav Smil. 1978. Taiwan Energy Plans Emphasise Electricity. Energy International 15(11):49-51; for Hawaii, Hawaiian Electric Company, Inc. 1978. 1977 Power System Statement. Report to the Federal Energy Regulatory Commission. Honolulu; for Luzon, letter from Conrado del Rosario, Sr. Vice-President, National Power Corporation, to H. Kurt Strass, National Research Council, August 30, 1979; for South Korea, Korea Electric Company. 1979. Electric Power in Korea 1979. Seoul, Korea; for Puerto Rico, Merrill Lynch White Weld Capital Markets Group. September 1978. Puerto Rico Water Resources Authority $32,000,000 Electric Revenue Bonds (Series 1978) $93,000,000 Power Revenue Bonds, Series E. New York.

The importance of taking these steps deserves emphasis. A concentrated effort to improve reliability can help postpone the date by which new capacity will be needed (though rising oil prices may justify fairly prompt replacement of some current capacity with new coal-fired capacity) and would contribute to the Island's economic health. Many industrial and commercial consumers depend critically on assured supplies of electricity; some have installed backup generators powered by oil to ensure reliability and others are considering such actions. Improving PREPA's service reliability will reduce the need for these relatively inefficient systems, thus helping to improve the efficiency with which petroleum fuels are used on the Island.

The problems described above make it difficult to avoid frequent brief interruptions in service and momentary fluctuations in voltage and frequency. Even in the San Juan area service is inadequate for automated industrial processes. In other parts of the Island, service to small residential and commercial customers is often interrupted for extended periods. PREPA management is aware of these problems, and recently began efforts to correct the situation by revising maintenance procedures, improving frequency control, and installing fast-reclosing circuit breakers and other equipment to lower the incidence and length of service interruptions. These steps have taken the general form recommended in this committee's interim report.

Rapid Response to Generating Outages

In an electric utility system, it is necessary to have generating capacity in reserve for immediate use if a major generating unit fails. Generally, the most economical source of such reserve is to operate some large units at slightly less than full capacity so that they can be throttled up within seconds to make up for lost capacity. This is called spinning reserve. Some utilities also use quick-starting units like gas turbines for somewhat less rapid response to outages (within minutes).

As indicated, responding quickly to outages is especially difficult in a system like PREPA's, with major units that are very large in proportion to the load at any given time. The loss of any one of the four largest units can instantly remove more than 20 percent of the system's generation, and there are no neighboring systems from which to borrow power. It would not be feasible to carry enough spinning reserve to make up for the loss of so large a unit. Nor is it realistic to maintain enough gas-turbine capacity for such duty. This is why most utility operators consider it unwise to install any generating unit with a capacity larger than 10 percent of the system's peak load. This limitation reduces the need for spinning reserve and other quick-response reserve capacity and thus increases the reliability of service.

With the generating units available to it, PREPA cannot maintain mainland standards of reliability. When one of the large generating units fails, the system will have to shed load to restore system frequency until other units can be brought on line. Even if the load drop is brief, customers with frequency-sensitive equipment such as rotary printing presses, automatic packaging devices, and other complex process equipment will suffer from the decline in frequency that accompanies a loss of generation.

Spinning Reserve

There is no fully satisfactory solution to the problem of outages, but it is possible to minimize the impacts. This committee recommends that the PREPA system's spinning reserve positions be enhanced by operating nearly all steam units at below full capacity. This would allow them to respond quickly to emergency demands and should reduce their maintenance requirements. Practically all steam units are already fitted with load frequency controls that automatically maintain constant generator speed under varying load conditions, so that no major capital expenditure would be required.

Quick-Response Capacity

PREPA should in addition designate certain quick-starting units for emergency standby duty. A forced outage often gives some minutes' warning, and the designated units could be started and synchronized in such a case before the failing unit is taken out of service. Using these units in such a manner will increase their maintenance requirements somewhat, so all quick-starting units should be loaded conservatively except in emergencies.

Selective Load Shedding

Fast-acting under-frequency relays should be installed throughout the system to shed selected loads immediately in case of generation losses. Such relays would permit noncritical customer loads to be dropped almost instantly, so that priority of service could be accorded users for whom a loss of load has severe economic or safety consequences. This procedure is commonly used on the mainland to protect hospitals and other vital services, and certain industrial processes that require very reliable service.

Without selective load shedding, the loss of a 400 megawatt generating unit when the total system load was 2,000 megawatts would produce the results shown in Figure 9. With no spinning reserve, as in the lower curve, there would be an immediate 25 percent overload of the

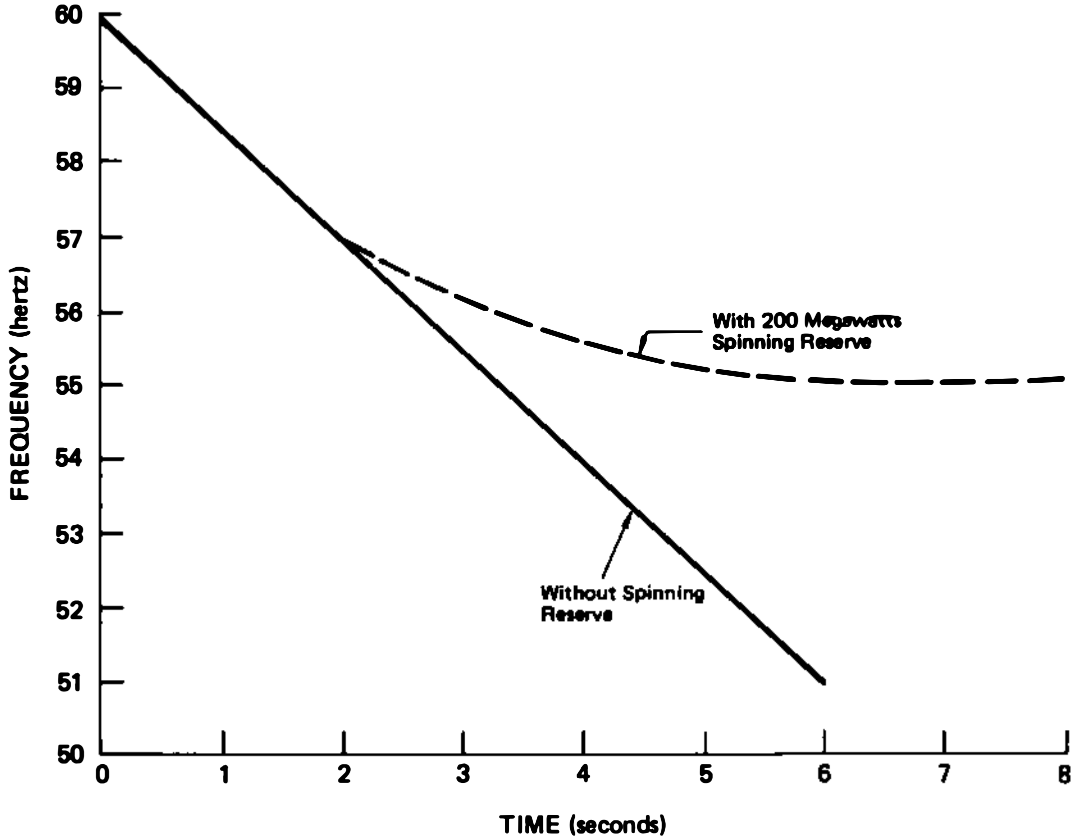


Figure 9 System frequency decay caused by the loss of 400 megawatts generating capacity, with a total system load of 2,000 megawatts, without load shedding, with and without 200 megawatts spinning reserve

system, and the frequency would decay from 60 hertz (Hz) at a rate of 1.5 Hz per second until about 6 seconds later, when a balance between the load and the generation was reached at 50.8 Hz. Nearly all electric motors connected to the system would have been severely damaged unless equipped with automatic overload current protection.

A 10 percent (200 megawatt) spinning reserve, as shown in the upper (dashed) curve of Figure 9, would slow the frequency decay and lessen its depth. It would take about 2 seconds for these reserves to be called up. At that time the overload would be 11 percent, and frequency would be decaying at the rate of 0.667 Hz per second. Equilibrium between load and generation would be reached at 55.0 Hz--too low for motor operation. (In actuality, some of the spinning reserve would be slow to come on line because of hysteresis and inertia in the mechanical governors and throttle linkages, and the course of events would lie between the two curves.)

Thus, even with a substantial spinning reserve, the system would fail unless some of the load were shed. With automatic load shedding devices, certain noncritical loads would be dropped less than 1 second after the loss of generation, so that a balance between load and generation could be achieved before frequency had decayed too much. Figure 10 is a representation of the frequency behavior of the system with and without automatic load-shedding. For purposes of illustration, the under-frequency load-shedding relays are assumed to drop 30 percent of the system load in three steps of 10 percent each, as the system drops successively to frequencies of 59.5, 59.0, and 58.5 Hz.

At the time of the generation loss, the initial frequency decline shown in Figure 10 would be the same as in Figure 9 (1.5 Hz per second). The first-step under-frequency relays would trip at 59.5 Hz, dropping 200 megawatts of load by the time the frequency had reached 59.3 Hz. At this point the system would be less severely overloaded, and the rate of frequency decline would be only 0.667 Hz per second. At 59.0 Hz, about 1 second after the trouble started, the second-step relays would be activated and would drop a second 200 megawatts by about 1.2 seconds after the initial overload, at which time the frequency would stand at 58.8 Hz. The system would remain in equilibrium at this frequency until the spinning reserve brought the frequency back to normal. The third set of relays would not be required in this situation.

At the stable frequency of 58.8 Hz, only especially sensitive equipment, such as rotary printing presses and unbuffered computer power supplies, would experience trouble; service to these would be protected. With 200 megawatts of spinning reserve, normal frequency would be restored within about 8-10 seconds. After stable system operation was achieved and additional generation capacity brought on line, the load would be judiciously restored.

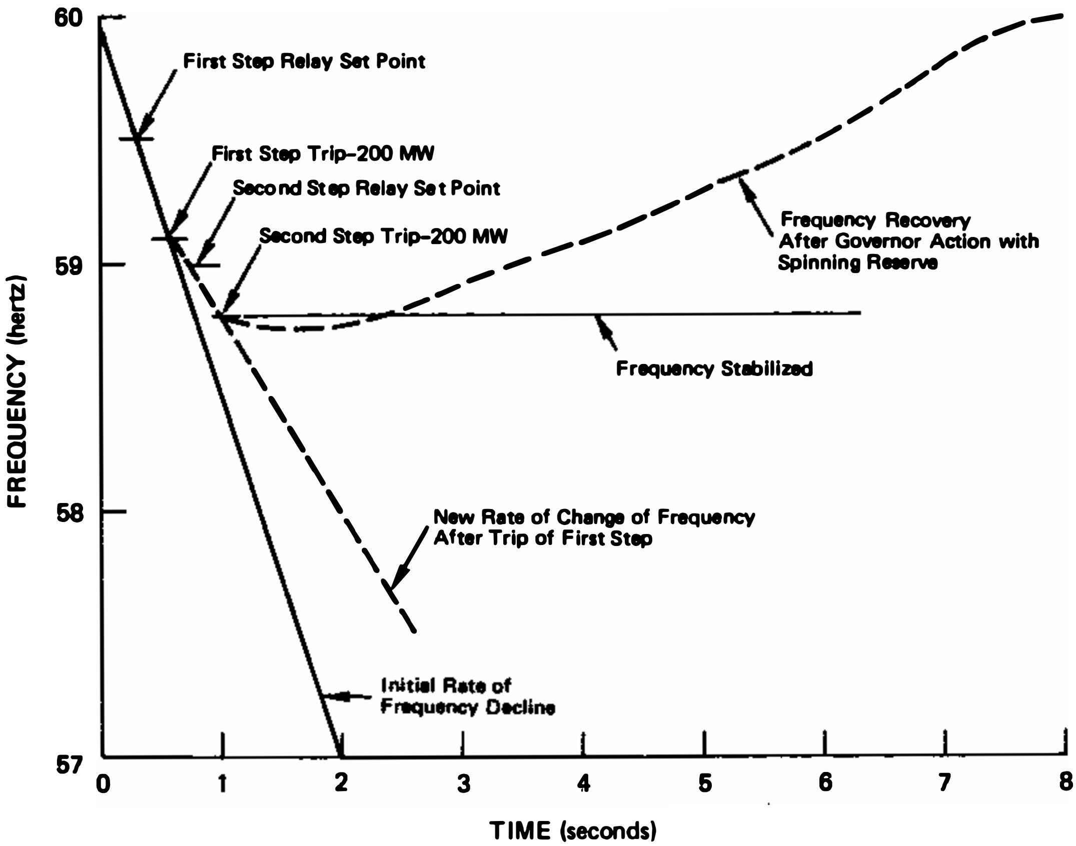


Figure 10 System frequency decay caused by the loss of 400 megawatts generating capacity, with a total system load of 2,000 megawatts, with selective load shedding

Improving Maintenance Procedures

Maintenance Schedules

Steam generating units of the type installed in recent years by PREPA normally must be shut down every three to five years for complete inspections, routine repairs, and overhauls. This is called a "unit overhaul" maintenance schedule.

PREPA, however, uses a "component overhaul" maintenance schedule, under which each major component (high-pressure turbine, low-pressure turbine, and generator) is overhauled separately. The result is that every large unit is shut down for some time each year. Units spends more time in maintenance under this schedule than if each were overhauled completely every few years.

For a system like PREPA's today, with a large reserve margin, a component maintenance schedule does not impair system reliability. However, it nearly always increases fuel costs, because the large units are generally the most efficient. If gas turbines--the least efficient units--are run to make up for the lost generating capacity, the fuel cost penalty can be high.

As reserve margins are reduced in the future, this maintenance approach, if continued, will increasingly impair system reliability. For example, results of reliability simulations[2] suggest that with a 60 percent reserve margin and a component maintenance schedule, the loss of load probability (LOLP) of the PREPA system would be about 17 days per year. Most mainland systems aim for an LOLP probability of only 1 day in 10 years. Much of the high LOLP record of the PREPA system is due to the quick-response reserve problem discussed earlier, but the LOLP of the system might be reduced to less than three days per year by adopting a unit overhaul maintenance schedule. Under such a program, each turbine generator would be scheduled for overhaul only every third or fourth year; boilers would undergo minor, two- to three-week overhauls at irregular intervals, once or twice each year.

Expediting Maintenance Work

In addition to adopting a unit maintenance schedule, PREPA should do disassembly work on a schedule of three shifts per day, seven days per week, whenever a unit is shut down for overhaul, so that the size of the overhaul job can be assessed as quickly as possible. Only when the unit has been disassembled can the overhaul job be precisely scheduled, taking into account the material requirements and detailed procedures. On a straight-time basis, five days a week, opening a steam turbine generator takes three to four weeks. Maintenance procedures should be modified to require that rotating elements be opened for inspection within seven days or fewer.

Performance Comparisons

Electricity generation, transmission, and distribution are common to almost all countries of the world. There are many opportunities for comparing costs and quality of service of different utility systems and of different individual generating units. Such comparisons help system operators to maintain the highest possible standards of reliability, efficiency, and economy.

The Puerto Rico Electric Power Authority should use such performance comparisons to stimulate competition among its own generating stations, in terms of monthly and year-to-date percentage availabilities, capacity factors, and unscheduled outage rates. These comparisons should be used to improve routine procedures and stimulate competition among the operating personnel of the different stations, with suitable rewards to the winning station's staff from time to time. Similar competitions might be arranged for the overhead line crews, perhaps in terms of relative productivity (worker-hours per standard construction unit).

FUTURE ADDITIONS TO GENERATING CAPACITY

Electric utilities throughout the United States have found it increasingly difficult to forecast the need for new capacity in recent years, as demand growth has slowed while licensing and construction schedules lengthened. In Puerto Rico these difficulties are exacerbated by deficiencies in operation and maintenance, an uncertain industrial outlook, and rapidly rising oil prices and interest rates. If existing capacity can be used more effectively, it should be possible to delay the date at which a new generating unit is needed, all other things being equal. A failure of the petrochemical and refining industry to grow would have a similar effect, by slowing the growth in the demand for electricity. On the other hand, rapid rises in the price of oil might make it economical to install new capacity earlier than it would otherwise be needed, if the new capacity were fired by a fuel cheaper than oil.

Clearly the decisions required in planning new capacity are very difficult, involving as they do these complicated tradeoffs. This committee is prepared to offer some general advice, but, as will be made clear, the best course of action will depend on detailed examinations of PREPA's operational difficulties and financial status, as well as careful assessments of such economic factors as fuel prices and contruction costs.

The Character and Timing of Future Additions

Fuels

There can be no question that the next large addition to PREPA's base load generating capacity should be fired with coal. Adding oil-fired capacity would be inconsistent with national objectives and would further expose Puerto Rico's electricity consumers to expected increases in the price of oil. Coal-fired generation is in any case generally cheaper than oil-fired generation at today's construction and fuel costs, and this advantage is likely to increase if OPEC oil imports are significantly curtailed. PREPA would have the advantage of competition for coal supply from several sources on the U.S. mainland and a number of foreign countries. It should be noted, however, that new operating and maintenance skills will be required in view of the relative complexity of coal-fired plants; also, if emission controls are required to meet air quality standards, substantial additional land will be needed for waste disposal.

This recommendation does not, of course, preclude PREPA's supplementing its generating capacity with new or reactivated hydroelectric capacity, onsite industrial cogeneration, or new sources of electricity from solar and other renewable sources; nor does it militate against upgrading existing oil-fired generators. These measures will all contribute to the Island's electricity supply before the year 2000, but they do not obviate the need for coal-fired base load capacity in the next decade.

With respect to nuclear energy, the Committee reaffirms the conclusion in its interim report that the nuclear option should be preserved as a possible component of Puerto Rico's future electric power system. However, considerations of both scale and timing rule out nuclear power for the next major addition to generating capacity. Moreover, as that report stated, "Unless economical small nuclear plants become available, it will be at least two decades before the Puerto Rico system becomes large enough to accommodate a nuclear unit.... In addition, the relevance of the nuclear option to Puerto Rico is likely to depend on the clarification of national policy in several respects, notably the procedures for siting and licensing plants, ensuring safety, and providing for spent fuel management and waste disposal."[3] It follows, therefore, that at an appropriate time toward the end of this decade, nuclear power generation should be reassessed as an alternative.

Timing

When the next significant addition to the Island's generating capacity will be needed is uncertain. As pointed out in this committee's interim report, it might be anywhere between 1986 and the late 1990's, depending on the growth in demand and on future reserve margin requirements. That report states that "we would expect the next addition to capacity to be needed on line in 1988 or 1989..."[4]

Since that report was written, however, the world oil market has tightened considerably, OPEC members have raised prices, and future oil price and supply prospects have worsened. Under these circumstances it may well be economical to build new coal-fired generating capacity simply to reduce the need for oil, whether or not the increased capacity is needed to meet growing needs. The least efficient oil-fired units could then be removed from service entirely or maintained for occasional emergency use. Even if such a move were slightly more costly, the increased use of coal would contribute to the national objective of reducing dependence on imported oil, and there is a possibility that federal assistance might be made available for this purpose.

The economics of such a shift to coal can be illustrated by a simple arithmetic example. Assume that long-term contracts for coal could be placed in the mid-1980's at $48 per ton (20 to 33 percent above present prices), and use 15 percent as the annual capital charge (interest plus depreciation). Assume heat rates (Btu's consumed per kilowatt-hour) to be 12,500 for oil and 10,500 for coal, and assume that the new unit would operate at an annual capacity factor of 60 percent (which may be on the low side). Given these assumptions, it would pay to replace still-serviceable oil-fired capacity by new coal-fired capacity if the price per barrel of number 6 oil exceeded $23-$25 with capital costs for coal-fired capacity at $1,000 per kilowatt. This threshold would be $30-$35 per barrel with capital costs for coal-fired capacity at $1,500 per kilowatt. The lower end of this oil-price range has already been reached for most oil in international trade, and even the higher end may soon be surpassed. (The current high interest rates would suggest the use of a somewhat larger capital charge rate, but would probably not substantially alter the conclusion.)

This committee considered the possibility of converting some of the existing oil-fired capacity to coal, in line with plans for a number of mainland power plants. In Puerto Rico, however, none of the oil-fired plants were designed for coal burning; neither their boilers nor their plant layouts are adaptable to the use of coal. Only at Aguirre would such a conversion be physically possible, and even there the economics of conversion would be dubious. This committee therefore does not recommend conversion of any of the existing units to coal.

Taking all these factors into account, this committee concludes that PREPA should continue for the time being on its present course, which would bring a new coal-fired generating unit on line by 1986. However, if electric load growth continues to stagnate or becomes negative, and if prices for residual oil stabilize or decline, this plan should be reassessed before construction begins. All construction contract awards should give PREPA the right to postpone scheduled construction and service dates at minimum penalties.

The Appropriate Capacity of New Units

This committee's interim report observed, "...it is not immediately clear that additional units of this (450 megawatt) size would be appropriate," and that "some (PREPA) studies point to 300 megawatts as the optimal size plant."[5] Further consideration of this has convinced the committee that about 300 megawatts is probably a more appropriate size than 450 megawatts, though the precise unit capacity should be selected on the basis of careful engineering and economic studies of the available alternatives, determined after competitive bidding. Three major considerations incline the committee to these conclusions:

- Uncertainty about future load growth. Growth in the system's load has slowed dramatically since 1974, and this trend has recently been reinforced by the closing of the PPG Industries Caribe chloralkali plant. Further uncertainties in the oil refining and petrochemical industries (Chapter 4) render unclear their potential for growth in electricity demand. Between 1974 and 1979, the peak load grew at a rate of only 2.5 percent per year; omitting the negative growth figure in 1975, the annual growth rate was 3.3 percent. Even if this rate should rise to 4 percent, a 300 megawatt unit would accommodate roughly three years' load growth. (Note that the higher energy demand projections in Chapter 3 estimate the rise in electricity demand at a rate of 2 percent annually to 1985.)

- Financing considerations. The availability and cost of capital are serious constraints on the continuing growth of the Puerto Rican economy. It is therefore important that PREPA exercise restraint in its demand for outside capital funds and defer the need for such funds as long as prudence permits. One way to do this is to minimize the size of the next addition to generating capacity. While that might point to units even smaller than 300 megawatts, economies of scale would likely militate against coal-fired units of less than that size. However, that question would be addressed in the proposed engineering studies, and requests for bids should provide a great deal of flexibility in specifying unit size.

- System operation considerations. For reasons described earlier, no single generating unit should ordinarily have a capacity greater than 10 percent of the system peak load. At a 4 percent annual growth rate, it would take 10 years for the PREPA system peak to reach 3,000 megawatts, the level at which a 300 megawatt unit would comply with this rule of thumb. At the same growth rate, a 400 megawatt unit would not be justified by this rule until 1996. Against this consideration, however, one must place the fact that PREPA already has four units with capacities larger than 400 megawatts. It can be argued, with a good deal of force, that adding one or two more 400 megawatt units would not seriously degrade the reliability of the generating system. This again suggests that further engineering studies may be needed before the final decision on unit capacity is made.

On balance, the forecasting uncertainties and financial problems seem important enough that, unless the economies of scale of larger units are very great, the preference should go to the 300 megawatt class. Reinforcing this view is an important but less tangible consideration; with the next unit Puerto Rico will be embarking on the operation of its first large coal-fired plant, the many new operating difficulties of which will be easier to cope with in a smaller plant.

In planning the new additions to capacity, PREPA should probably make arrangements for at least two units of the size and type selected (presumably 300 megawatt coal-fired base load plants) at the same site, even though their service dates may be widely separated. Building duplicate units at a single site will likely cut costs substantially.

Siting and licensing work, preparation of environmental impact statements, and the like will take several years. Meanwhile, boiler and turbine bids can be solicited and evaluated, engineering studies can be done to select the most appropriate size and type of units, pollution control alternatives can be evaluated, and long term coal supplies can be located and contracted for. Optimum boiler designs for the type of coal contracted for (or that likely to replace it in case of supply interruptions) can then be selected.

A final decision on the service date for the next addition to capacity can probably be deferred for two years, if no steps inconsistent with licensing and construction by 1986 are taken. If all licensing and siting problems are resolved, and major facility components are contracted for in time for ground breaking to take place by January 1, 1981, or shortly thereafter, the first unit could be in place by mid-1986. This would allow five years for construction, and six to eight months for shakedown operations.

Financing

This committee's interim report, in discussing the Puerto Rico Electric Power Authority's financial position, called for steps, "to improve internal cash generation, which in recent years has rarely been large enough to cover even routine construction expenditures."[6] It recommended that rates be increased enough to raise about $60 million (of 1979 value) per year, in addition to any increases needed to cover rising costs of fuel, labor, and other operating expenses.

Developments since that report give added force to that recommendation. During the fiscal year ending June 30, 1979, PREPA operations sustained a net loss, after deductions for depreciation computed on the basis of historical costs (which are probably less than half current replacement costs), interest, and payments in lieu of taxes. PREPA yielded no return on Puerto Rico's original investment or on agency investments and capital funds accumulated from prior years' earnings. Indeed, PREPA had to borrow $69 million merely to operate and make routine capital investments.[7] The outlook for fiscal 1980 shows no improvement. Net borrowings are projected by PREPA at $104 million, again without major capital additions.[8]

The consequence is a significant deterioration in the financing environment for the future capital expansion needs of PREPA, with the potential for repercussions on Puerto Rico's borrowing capacity for other public needs. In mid-October, the Authority's $100 million tax-exempt bond issue was sold at a net cost of 9 percent, compared with issues of the New York State Power Authority carrying the same nominal credit rating but costing only 8 percent. The debt service coverage ratio (the ratio of net revenues to total debt service requirements) has fallen since 1975 from 1.73 to 1.63 and the pro forma figure for the last 12 months, reflecting the new bond issue, is only 1.46.[9] This is uncomfortably low in the eyes of bond market specialists. PREPA will need to borrow $200 million to $300 million annually in the early 1980's to finance major additions to its generating capacity. Action to strengthen its financial position is therefore of growing urgency. For all practical purposes, this means raising rates.

Rate increases in Puerto Rico since the oil price rise of 1973 have been smaller than those of many mainland utility systems, even though the Island has felt the effects of that price rise more severely than any region of the mainland. In fact, with the government subsidy, residential rates in nominal terms have remained virtually unchanged since 1974, the year in which the first effects of the 1973 OPEC price rise were felt--a substantial decrease in real terms. In the meantime, the average residential rate increase on the mainland has been 42 percent.

This committee recognizes the difficulty of raising rates in the face of mounting unemployment. It also realizes that, despite the modest increases of recent years, Puerto Rican rate levels are already higher than those of most mainland systems. However, this reflects the Island's nearly total dependence on high-cost oil as fuel for generation. PREPA must raise its rates if it is to finance its future construction program.

SOME GENERAL RECOMMENDATIONS ON PREPA MANAGEMENT

This committee has not examined the Authority's management and organization in the detail with which it has treated the operational and financial situations. Nonetheless, based on the experience of mainland utilities, it offers here some general observations:

- Because of their complexity, large construction jobs offer unusual opportunities for collusion and fraud. As PREPA embarks on a large construction program, it will want to establish consistent procurement and contracting practices and administer them under the direction of an experienced negotiator, independent of the engineers and operators. Moreover, as field construction work gets under way, an independent audit staff should be established at the site.

- Establishing the independence of financial, purchasing, and audit activities from the physical operating organization by placing these activities under the control of a single financial officer reporting directly to the Executive Director would increase the effectiveness of the construction controls referred to above. It would also be consistent with the internal control objectives of the Federal Corrupt Practices Act.

- It has become common practice on the mainland for regulatory authorities to engage outside consultants to audit the management performance of utility companies under their jurisdictions. The Board of PREPA may wish to consider such a step. Such audits would cover matters of organization, operation, planning, and financial management and would be in addition to the standard outside accounting audit that is part of PREPA's normal practice.

NOTES

1. National Research Council. June 1979. Interim Report of the Committee on Future Energy Alternatives for Puerto Rico. Energy Engineering Board, Assembly of Engineering. (Washington, D.C.: National Academy of Sciences). p. 2-3, 5-6.

2. Personal communication. David J. Fogarty, Southern California Edison Company, to John O. Berga, National Research Council May 17, 1979.

3. National Research Council. June 1979. Interim Report of the Committee on Future Energy Alternatives for Puerto Rico. (note 1). p. 9. For a detailed discussion of nuclear power technology and policy over the next three decades, see the report of the National Research Council Committee on Nuclear and Alternative Energy Systems (National Research Council. 1980. Energy in Transition, 1985-2010. San Francisco: W.H. Freeman and Company. Chapter 5.)

4. National Research Council. June 1979. Interim Report of the Committee on Future Energy Alternatives for Puerto Rico. (note 1). p. 9.

5. National Research Council. June 1979. Interim Report of the Committee on Future Energy Alternative for Puerto Rico. (note 1). p. 12.

6. Merrill Lynch White Weld Capital Markets Group. October 1979. $100,000,000 Puerto Rico Water Resources Authority Power Revenue Bonds, Series F. Official Statement. p. 17.

7. Merril Lynch White Weld Capital Markets Group. October 1979. $100,000,000 Puerto Rico Water Resources Authority Power Revenue Bonds (note 6). p. 20.

8. Merrill Lynch White Weld Capital Markets Group. October 1979. $100,000,000 Puerto Rico Water Resources Authority Power Revenue Bonds (note 6). p. ii.

6 ENERGY CONSERVATION OPPORTUNITIES

On the mainland, the benefits of energy conservation have earned the status of accepted wisdom. No responsible report now omits the conventional litany of praise: "clean," "quick," "economical," "inflation proof," and "environmentally benign." In Puerto Rico also, energy conservation is essential to sound economic growth with assured energy supply. Puerto Rico feels many of the same incentives to conserve as the mainland. Federal energy-efficiency standards and labeling requirements, for example, apply in Puerto Rico, and it goes almost without saying that the effects of higher oil prices are felt in Puerto Rico with an intensity unmatched on the mainland.

This discussion may be suggestive, instructive, and informative about energy conservation possibilities in Puerto Rico, but success must come from local ideas, developed and implemented with attention to the system within which they must work. Energy conservation, considered as an energy source, is unlike conventional centralized energy sources in that it depends on the actions of thousands of individuals, each making hundreds of decisions for wide varieties of reasons. Energy conservation is influenced strongly by local cultural and economic conditions, to which effective conservation policy must be accommodated. The careful studies of conservation undertaken by the Puerto Rico Office of Energy, and the generally high priority the government of Puerto Rico has accorded energy conservation, are encouraging.

Puerto Rico uses about 40 percent of its oil imports to generate electricity, about two-thirds of which is used in the industrial and commercial sector and the rest in residences. Transportation accounts for about 30 percent of the Island's direct oil consumption, industry and commerce for about 25 percent, and residential consumption for about 1 percent. The remainder, about 4 percent, is consumed in the form of nonenergy products.

This chapter discusses four issues:

- Energy conservation in transportation. Although both the Federal automobile fuel efficiency standards and the growing proportion of fuel-efficient imported cars in Puerto Rico will work to reduce the energy devoted to transportation, policy actions taken by the government to make public transportation more attractive and to impose the full costs of driving on those who choose to do so can add to the savings available from such engineering solutions.

- Energy conservation in buildings. Puerto Rico's new building code and the federal Building Energy Performance Standards (to be imposed nationally within a year or so) will both lower energy consumption in new buildings. Savings are possible also from an intelligent program of retrofitting existing housing stock and from improving the ways in which commercial establishments use energy. Hotels hold especially attractive opportunities.

- Energy conservation through electricity rate reform. The object of an efficient rate structure is to charge customers the costs of electricity they consume and provide them the savings from electricity they conserve. The Puerto Rico Electric Power Authority's rate structure can be reformed to bring it closer to this ideal.

- Cogeneration of electricity and steam. The simultaneious production of electricity and steam for relatively low temperature heating presents an opportunity for fuel savings on the Island. However, the planning and institutional barriers are large.

In Puerto Rico, as elsewhere, large industrial energy users are capable of making effective process and housekeeping changes in reaction to rising energy prices. The best industrial energy conservation policy is to avoid shielding industry from rising prices. Higher energy prices are inescapable, and intelligent investment decisions will be possible only when energy users confront the costs of consuming energy undiluted by government action. For industrial users, for example, the special promotional electricity rates should not be renewed when they expire.

The recommendation that government stay out of direct energy conservation programs for industry is tempered somewhat in the case of smaller industrial and commercial businesses, to whom the lack of information may be an impediment to effective conservation. As the federally funded Energy Extension Service grows in reach and sophistication, it may provide some of the needed help. Technical information programs based in universities have been successful in some mainland areas. Any program that can provide specific how-to information to smaller businessmen is worth pursuing aggressively; energy audits and similar information programs, for example, will pay large returns by spurring individual intiative. However, no government policies should shield even these small businesses from higher energy prices.

ENERGY CONSERVATION IN TRANSPORTATION

In Puerto Rico, the transportation is almost entirely by highway. The ratio of vehicles to people is about one to four (half that of the mainland) but by 1995 may reach one to three. About half the present fleet is located in the San Juan metropolitan area. Public transportation is poorly coordinated, has a declining ridership, and serves non-work-related travel (an important component of demand) relatively poorly. Obviously it would be to Puerto Rico's economic advantage for as many drivers as possible to turn to other, more efficient, forms of transportation and for the automobiles that are used to increase in efficiency. The policies of the Puerto Rican government will largely determine the extent of this transition, though oil price trends and national fuel-efficiency regulations will play their parts in lowering gasoline demand.

Efforts to improve the energy efficiency of Puerto Rico's transportation system will entail two coordinate strategies: making public transportation more attractive as an alternative to the automobile, and at the same time imposing penalties (in both travel time and dollars) on inefficiency in private transportation. The two must be undertaken simultaneously, and with corresponding vigor, or neither will be effective.

The effectiveness of most of the public-transportation-oriented measures discussed in this report will be limited by continued increases in real personal income and the accompaying rise in automobile ownership. The most effective single conservation measure under these conditions is the continued improvement of new car fuel economy, driven by a combination of increased gasoline prices, the fuel economy standards of the Energy Policy and Conservation Act, and the vehicle excise tax schedule. The effect of the latter two factors alone is expected to result in an improvement in the fuel economy of the entire Puerto Rico fleet by more than a factor of two by the year 2000. This factor is reflected in the baseline energy forecasts of the committee.

Increasing the Attractiveness of Energy-Efficient Transportation Modes

Improving bus service, truly integrating the publicos into the public transportation system, and providing alternatives like van pools where feasible to serve the needs of government workers or other easily formed groups can go far toward luring drivers from their cars at relatively low cost to the Puerto Rican government. A true transportation system is needed.

A Rationalized Public Transportation Network

In 1970 the Metropolitan Bus Authority (MBA) operated 13 million bus miles and transported 60 million passengers. In 1977, operating almost as many vehicle miles, it transported only 35 million passengers, fewer than the number estimated to have been carried by publicos. Even at this lower level of ridership the bus system is more energy efficient than private cars at typical occupancy rates, but without very significant improvements in service the downward trend in ridership may continue until the bus system is no longer a real alternative.

The bus system has 47 routes, many overlapping, which have been laid out in an apparent attempt to serve every neighborhood from every other neighborhood without a transfer. There are no true express routes, and only a few routes can capitalize effectively on the priority bus lanes between San Juan and Rio Piedras. Sixty percent of the routes (generally those lying north of the Avenue of the 65th Infantry) transport 92 percent of the passengers. The rest of the routes operate at extremely low load factors through areas served mainly by publicos.

A more rational system would consist of a trunk line with true express buses operating as much as possible on priority lanes in the corridor linking San Juan, Rio Piedras, and Carolina, with a westward spur to Bayamon. This trunk system would be supported by a series of feeder lines. Although many trips would then require transfers, the total elapsed time for most trips would be significantly reduced and the system would become a real alternative to the automobile. Such a system also should be capable of operating with fewer vehicle miles for a given capacity and level of service.

If public transportation is to operate as a true system, the publicos should be integrated into the network, to serve as feeders in neighborhoods where full-size buses are not warranted. The problem of poor off-peak service must be addressed if publicos are to be thus integrated into a revised system. Adequate service could be ensured by issuing subsidized transfers from and to MBA express buses, or by selling off-peak publico tickets at the regular publico fare but redeeming them from publico drivers at a premium.

The MBA has made a cautious start at rationalizing its system by constructing the Carolina transfer facility and proposing the substitution of feeder buses for certain of the through routes that serve the Country Club and Carolina areas. A comprehensive system (including the publicos) can be built only by the cooperation of several government entities. This should be accorded a high priority by the transportation task force established by the Governor.

A Revised Taxi Fare System

The present taxi rate structure prohibits collection of multiple fares for the same trip. A revision of this structure, accompanied by promotion of shared riding, particularly on long trips such as those originating at the airport, could save fuel. In Washington, D.C., for example, shared rides are permitted, at the passengers' discretion, and multiple full fares are charged. In New York City and Boston, shared taxi systems have been developed for riders traveling from airports to the central cities.

Subscription Park-and-Ride Service

During a six-month period in 1978-79, the Puerto Rico Office of Energy conducted a pilot project, transporting employees of the Minillas Government Center in Santurce by bus from the Juan Ramon Loubriel Stadium parking lot in Bayamon. This service competed with the availability of inside parking spaces in Minillas, priced at $13 per month. An average of 80 participants used this service daily; the project was terminated because of lack of funding. The Department of Transportation and Public Works is now beginning a new project with funding provided by the U.S. Department of Transportation. The Office of Energy has estimated that an expanded service to Santurce and Hato Rey from Bayamon and Carolina would have saved approximately 20,000 barrels of fuel per year.[1] Eliminating subsidized parking for employees would probably increase the use of such alternative services.

Employment-Based Van and Car Pools

Prior attempts at van pooling by several employers have been unsuccessful; employees prefer the flexibility of individual cars. Increasing gasoline prices could make such services relatively more attractive, and this concept should be retested.

Establishing Incentives for the Efficient Use of Automobiles

Even a much more effective public transportation system will yield small energy savings to Puerto Rico unless the government is able to apply some pressure on drivers to drive less, by such economical means as enforcing parking regulations more consistently, raising parking fees and gasoline taxes gradually, and redirecting transportation investments from highway construction toward facilities for alternatives to the automobile. The Puerto Rican government can at the same time take measures to encourage those who still choose to drive to reduce their gasoline consumption by driving more fuel-efficient cars. Each of these measures would tend to raise the cost of driving, in inconvenience if not in dollars; if such a program is to have benefits in terms of reduced oil consumption it must be combined with a serious effort to revive the public transportation system. It would also be appropriate to compensate in some way those, especially the less affluent, who must drive.

Federal automobile efficiency standards will have a major impact on gasoline demand. By the year 2000, it is estimated (Chapter 3) that the Puerto Rican fleet's fuel economy will average 25 miles per gallon. By 1985 total demand should be about the same as in 1977; thereafter, this study's projections indicate little or no increase, depending on the particular growth scenario. These changes will occur without any direct policy action by the Puerto Rican government. One can, however, look to actions other than vehicle efficiency standards to increase costs and lower hidden subsidies.

Fuel-Economy-Based Excise Taxes and Registration Fees

Under present law, new and used passenger cars imported into Puerto Rico are subject to an excise tax ranging from 14 to 85 percent of their values, depending on weight and horsepower. This tax does not correlate precisely with fuel economy; nor is it perceived as an efficiency tax. The Office of Energy has prepared a bill, supported by the Governor, that would substitute a tax schedule based on the U.S. Environmental Protection Agency estimates of vehicle efficiency. The bill would substitute a tax varying from 7 percent (for a car achieving 30 miles per gallon) to 85 percent (for a 13-miles-per-gallon car). If adopted, it would reduce fuel consumption by about 400,000 barrels per year.[2] We support the general goals of such a bill, though we have not examined the bill in any detail.

Parking Charges and Enforcement

The price of parking in the San Juan metropolitan area is controlled by the Department of Consumer Affairs, whose primary aim is to minimize the impacts of inflation on consumers. Parking rates are generally less than $15 per month, significantly below those in comparable metropolitan areas on the mainland. These low prices encourage the use of automobiles for trips that might otherwise have been made by public transportation. A study of these rates might reveal the possibility of large gasoline savings from relatively modest rises in rates. If this hypothesis is correct, a gradual removal of controls, or at least a rise in the controlled price, should be considered.

Compounding this situation is the extremely inadequate enforcement of parking regulations in the metropolitan area. Illegal parking spaces add some 10,000 units to downtown San Juan's legal inventory of 40,000.[3] Towing is almost nonexistent; the fine, when imposed, is $7 per offense. Recent experience with improved parking management in the Washington, D.C., downtown area demonstrates that vigorous programs of ticketing, towing, and collecting unpaid fines (by, for example, refusing to renew license tags until outstanding fines are paid) can be effective and self-financing.

The Price of Gasoline

Estimates of the price elasticity of demand for gasoline (that is, how much less gasoline motorists will use when faced with a given price increase) vary rather widely. The short-term elasticity is a measure of the willingness of people to react quickly by deferring trips, taking shorter trips, or combining trips; its value is often cited as -0.2 (meaning that in response to a 1 percent price rise, gasoline consumption falls by 0.2 percent). The long-term elasticity, which measures changes in behavior after people have been able to buy more efficient cars, change work places and residences, or adjust to expanded public transportation systems, ranges from -0.8 to -1.0. No matter what the exact figure or range, there is little doubt that price rises are effective inducements to conserve; substitutions are possible, and alternatives can be found.

The price of gasoline in Puerto Rico ($1.33 per gallon for leaded and $1.29 per gallon for unleaded as of February 1980) includes $0.16 per gallon in Puerto Rico Tax and no federal tax. Although it would no doubt be politically unpopular, we suggest that the gasoline tax should be increased by pre-announced steps over a number of years (say five) so that consumers would be able to plan in advance measures to avoid increasing their transportation expenditures. One interim target might be to bring the Puerto Rican tax on gasoline up to equal the level of state plus federal taxes on the mainland. A staged imposition of this tax would also give the transit authorities time to implement the improvements in service suggested later in this chapter.

Some way of subsidizing low-income families to cover a part of the resulting rise in gasoline prices ought to be considered, because the automobile is for many the only truly usable means of transportation. Some have suggested a two-tier system in which lower income families are given gasoline stamps. We favor instead simply an increase in general welfare payments by an amount calculated to cover the increase in tax for a certain minimum automobile use. Lower income families would then be able to take advantage of the least costly transportation alternatives, using this increase in payments, and would not be locked into an increasingly costly automobile-based transportation system, as they would be if given gasoline stamps.

Redirecting the Proceeds of Highway Taxes

The gasoline tax collected in Puerto Rico is now used solely for constructing and financing new highway facilities. All maintenance activities are paid for by revenues from the general fund. Under present circumstances, this policy appears counterproductive. The proceeds should be reallocated away from new construction into the general fund or (second best) into highway maintenance and construction of facilities for buses, car and van pools, bicycles, and the like.

An ongoing program, funded by the U.S. Department of Transportation through the Federal Highway Administration, involves efforts to smooth traffic flow and reduce stop-and-go driving and idling time by constructing right and left turn lanes, widening roads, and coordinating traffic signals. It is expected to be 40 percent completed in Puerto Rico by 1980; the Office of Energy estimates it will then save 150,000 barrels of oil per year.[4]

Unfortunately, this program is an example, in our opinion, of spending money for a short-term benefit when a better long-term solution to urban transportation is available. Automobile drivers select paths through a highway network that results in minimum travel time from origin to destination. Thus, as improvements are made in one link of the network, reducing travel time in that link, drivers will switch from alternative paths until the increase in traffic has raised travel time in the improved path up to equilibrium with others. Such traffic engineering improvements can in the long run attract more traffic to the network.

Several more productive investments could be made with the proceeds:

- Priority lanes. A single lane in each direction in the corridor between Old San Juan and Rio Piedras has been established for the sole use of buses. Although parts of 20 bus routes operate over this lane, it represents a relatively small portion of the mileage on most of these routes and therefore has little impact on overall travel time. The priority lanes should be expanded as the public transportation system is rationalized. Permitting other multiple-occupancy vehicles, such as taxis and publicos, into these lanes shold also be considered.

- Transfer terminals. The Metropolitan Bus Authority has recently completed a building near Carolina, as a transfer terminal between a trunk line express bus system and a series of feeder lines. The facility's opening has been delayed pending the completion of public hearings on the necessary route restructuring. Additional facilities of this nature will be essential to a restructured transportation system, and planning and construction should proceed.

- Bicycle facilities. In spite of its relatively level topography and a climate that is generally conducive to bicycle use, the San Juan metropolitan area has no paths intended solely for the use of bicycles. A study of a proposed bicycle path extending from Old San Juan along the shore through the Condado area is underway, but this appears to be intended mainly for recreational use by tourists. It would probably not be prudent to build extensive bicycle paths without first testing the willingness of San Juan residents to use them. A good first step, if the Condado path is built, might be to provide protected bicycle storage facilities and showers for employees at the Condado hotels and other business establishments to test their acceptance of bicycle transportation.

Institutional Issues in Transportation

Puerto Rico's transportation system is controlled by a number of government agencies, with different or even conflicting missions. The Department of Transportation and Public Works is responsible for constructing and maintaining highways and other public facilities and for administering federal highway and transit funds. The Metropolitan Bus Authority owns and operates the public transportation system of the San Juan metropolitan area, except for the publicos. The Public Service Commission regulates publico routes and fares. The Department of Consumer Affairs controls the rates charged for parking. The Office of Energy is responsible for developing energy policy, including conservation programs, and for administering federal and Puerto Rican energy funds. Even if each agency performed its own mission perfectly, the result would not be a system optimized for energy efficiency. The Director of the Office of Energy recently was asked by the Governor to organize a task force of senior representatives of each of the involved agencies, charged with developing a plan for transportation. This appears to be a necessary first step in implementing many of the measures recommended thus far.

ENERGY CONSERVATION IN BUILDINGS

On the mainland, buildings represent the major opportunity for energy conservation. Many of the conventional solutions in the United States, however, are not appropriate for Puerto Rico, with its warm, humid climate and typically low household energy use. The physical and economic facts require that the Puerto Rican government develop measures suitable for the Island, rather than drawing heavily on work performed elsewhere. Residences consume only about 13 percent of the energy used in Puerto Rico, and thus do not offer dramatic energy savings to the Island as a whole, but important savings to the individual consumers are available at reasonable cost.

Energy Use in Puerto Rican Buildings

Puerto Rican dwellings generally consume less energy than do their mainland counterparts. Half of Puerto Rico's dwelling units consume less than 300 kWh per month, and only 5 percent consume more than 700 kWh per month. Consumption levels in San Juan are on the average about 20 percent higher than in rural areas. Conservation measures in rural areas and in urban dwellings that use little power will improve internal living conditions but not yield significant energy savings.

Puerto Rican homes generally have fewer energy consuming appliances than the average mainland home. Table 42 is a tabulation of the appliances penetration, by electricity consumption levels, in the San Juan metropolitan area. The basic low-consumption appliance mix consists of a refrigerator, a clothes washer, and a television. Somewhat more than half the residences use electricity for domestic water heating. Any significant use of air conditioning would push consumption above the subsidized level of 425 kWh per month.

The typical single-family residential building has poured-in-place concrete or block walls and a flat slab concrete roof with no insulation or attic space. Homes are not heated, and few have air conditioning. Where used, air conditioners are mainly through-the-wall units; ventilation is typically provided by jalousie windows. The percentage of homes with air conditioners--the most energy-intensive appliances whose use might reasonably be expected to grow markedly--is unlikely to more than double by the end of the century, even under the high growth assumptions of our Case A (Chapter 3). Electricity use for space cooling might as much as triple by the year 2000, but it would still represent a relatively small percentage of household energy use, and an almost insignificant percentage of the Island's energy use.

In multi-family construction (both public housing and privately financed units) concrete construction again predominates. Public housing is not air conditioned. About half the privately owned multi-family buildings are air conditioned, usually with through-the-wall units.

Data on nonresidential buildings are more difficult to gather. A consultant to this committee reported on resort hotels as targets for energy conservation and found that they are generally similar to their mainland counterparts. Of the 38 hotels, 26 (representing 78 percent of the guest rooms) are in the San Juan Metropolitan Area. Extrapolating from limited data, the consultant estimated that these 26 hotels consume annually about 60,300 barrels of oil used directly and 164 million kWh of electricity.

Table 42 Percent of Puerto Rico Electric Power Authority customers owning various appliances--San Juan metropolitan area[a]

Usage in kilowatt-hours per month	Percent of customers owning appliances									
	Refrigerator	Electric range	Gas range	Clothes washer	Television	Electric water heater	Solar water heater	Dishwasher	Air conditioner	Central air conditioner
1-425[b]	100.00	35.85	59.19	73.70	92.93	56.16	0.00	0.60	14.15	0.00
426-1,000	99.27	75.46	21.24	93.41	98.80	88.28	0.00	4.40	58.24	0.37
Over 1,000	100.00	90.42	8.98	99.40	98.20	93.41	1.20	28.14	96.41	3.59
Average consumption by appliance (kilowatt-hours per month)	90	100	0	15	50	200	0	30	340	850

[a]Gas rate customers (regular residential rate). Low rent public housing customers are not included.

[b]For computing subtotals and total percentages, the data for each individual strata were weighted to account for its population relative to the other intervals (frequency distribution of population (percent) in San Juan metropolitan area by kilowatt-hour intervals of October 1976).

Source: Correspondence from Jose Marina, Puerto Rico Water Resources Authority, to F. Castellon, Director, Puerto Rico Office of Energy, April 24, 1978. Results derived from a survey conducted from December 1977 to February 1978.

Regulatory Framework

Puerto Rico has recently adopted a building code that applies to construction of all new public buildings (buildings used by the public, with the exception of public housing). The technical basis for the code is Standard 90-75, developed by the American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. (ASHRAE), and modified in some respects to make it more suitable for the local climate. Adoption of the code was encouraged by the U.S. Department of Energy, acting under legislation giving it the power to withold payments to the Office of Energy if such a code were not adopted.

Puerto Rico, along with the other American jurisdictions, may soon be required to adopt a different code, the so-called Building Energy Performance Standards (BEPS). Instead of specifying, as the ASHRAE standard does, characteristics of building components that, taken together, will produce a suitably energy-efficient building, the BEPS will require that any new building design be analyzed as a whole to determine in advance whether it will use less than a certain mandated number of Btu's per square foot per year, depending on the climate zone and building classification. The U.S. Department of Energy released the BEPS as a proposed regulation in late November, 1979 (44 Federal Register 68120, November 28, 1979) with the intention of promulgating final rules in August 1980. At that time, the United States Congress will have the option of making the BEPS rules mandatory in all jurisdictions. If made mandatory, BEPS will preempt other nonequivalent local energy standards for new buildings.

Other federal standards apply to household appliances, including hot water heaters, air conditioners, refrigerators, and stoves. However, progress in implementing these standards has been slow. Moreover, the rate at which new appliances are introduced into the Puerto Rican economy appears slower than on the mainland. Taken together, these two factors will make the federal appliance standards less important in conserving energy than they are on the mainland.

Recommended Strategies for Existing Buildings

Residential Units

A variety of measures can be taken, in dwellings that are air conditioned or not, to increase comfort and--in air conditioned buildings--save energy that would otherwise be spent in cooling. A variety of awnings, interior and exterior shading devices, and reflective glazes for windows, for example, is available. Roofs can be insulated to reduce their absorption of the sun's heat. Except in dwellings in which the air conditioners are run throughout the afternoon and evening hours, though, only the simplest and least costly of these measures are economical for the homeowners as means of saving electricity. The largest savings, obviously, lie in running air conditioners more sparingly, such as only during sleeping hours, or avoiding the need for air conditioning altogether by relying on natural air circulation.

The typical home in Puerto Rico, in fact, is equipped with jalousie windows to take advantage of the fairly constant easterly trade winds, which average 9 miles per hour. This practice deserves to continue, though the problem of associated air infiltration must be corrected in air conditioned dwellings. Cracks where jalousie panes meet can admit warm, humid air. In one calculation for an 800-square-foot dwelling with the indoor air conditioned to 75°F and 60 percent relative humidity and the outside air at 83°F and 75 percent relative humidity, and with 10 hours per day of air conditioning use, installation of vinyl sealing strips on the edges of the panes reduces energy consumption by 70 kWh per month.[6] Vinyl stripping is relatively inexpensive and can be installed easily. This might result in a saving of as much as $55 per year per dwelling unit. It is quite cost effective.

Resort Hotels

The 38 resort hotels in Puerto Rico appear to have been built with little attention to energy consumption. Each differs slightly from the others so that it is hard to generalize, but the number of hotels is so small that a program of targeted energy audits appears possible. The Puerto Rico Office of Energy has included energy audits as one of the measures in its conservation program. The Office estimates that by 1980 4 to 5 percent of all commercial buildings will be audited, and that this measure will result in a saving of 28,300 barrels per year.[7] Studies on the mainland have suggested that savings of 30 to 60 percent can be achieved with existing buildings subjected to careful audit, constrained by the requirement that all changes be cost-effective to the building owner. Energy audits of resort hotels should be accorded high priority.

Implementation Strategies

Energy conservation in existing buildings is easy to discuss in the abstract, but it has proven much more difficult to achieve. The Puerto Rican government must pursue as aggressively as possible every opportunity to encourage or require building owners to upgrade their buildings. We believe that some of the following actions should be tried:

- Training and deploying "house doctors." Various strategies have been suggested for training and putting into the field paraprofessionals trained to look for building energy deficiencies, to correct those that are easy to handle on the spot, and to provide accurate, concrete advice on more expensive or time-consuming items. A program to provide such technicians would establish employment opportunities in a service industry; the number of buildings to be audited is large enough to support a good number of such jobs. The government could help establish such an industry in Puerto Rico by providing specialized training and by subsidizing PREPA to provide this service at little or no cost to its customers.

- Training building inspectors. We have made no independent inquiry into the subject in Puerto Rico, but if the Island is typical its building inspectors have virtually no training in energy conservation. Training courses are necessary for those enforcing the law and the new Building Energy Performance Standards.

- Offering tax incentives to building owners. Various federal income tax incentives are available to mainland citizens who make specified improvements in the energy efficiency of their dwellings. Puerto Rico might consider adopting a similar program.

- Informing the public. The vigorous information compaigns by the Office of Energy should be continued. Specific and practical information is more valuable than mere exhortation.

- Reconsidering architectural styles. Although this is a somewhat longer range conservation strategy, the committee is struck by the fact that many of the newer buildings in Puerto Rico appear to be copies of common mainland architectural styles. In contrast, many older buildings, like the Fortaleza itself, draw on architectural styles that minimize energy use. Such "design with nature" deserves a reevaluation in light of higher energy costs. Of course, not all traditional design features are appropriate to this century, but we urge the university and the private architectural design and engineering communities to reconsider some features of older buildings for adaptation in new ones. Perhaps the Puerto Rican government could help by sponsoring a conference drawing the design community together to discuss this approach.

Conclusion

Energy conservation in buildings will take effect slowly in Puerto Rico, and it represents a substantially less significant opportunity than on the mainland. Puerto Rico can learn from mainland areas with similar climates, but much of the responsibility for developing new strategies and implementation techniques will fall on the Office of Energy.

ENERGY CONSERVATION THROUGH ELECTRICITY RATE REFORM

On the mainland, interest in electricity rate reform as a means of conserving energy has risen along with the price of fuel. The principle is simple; to the extent possible, rates should reflect the costs of producing and distributing electricity. At times of day, for example, when demand is high, fuel costs are generally driven up by the use of relatively inefficient "peaking" units to generate the final few increments of power. Many have recommended that rates be set to rise generally during peak demand periods, to reflect these higher marginal fuel costs. Similarly, as overall demand for electricity rises, utilities must add new generating capacity, generally at higher cost then the average of existing capacity. There is some justice in the suggestion that the final increment of electricity consumed by a large user should be charged at a higher rate to reflect this marginal capacity cost. Each of these rate practices would impose on customers financial incentives to conserve, and would thus tend to lower the marginal costs of both fuel and capacity. In addition, they could be justified as ways of more accurately matching rates to the cost of service.

At present, most of PREPA's residential, industrial, and commercial rates are charged on declining block structures. That is, each increment of electricity to a given consumer is charged at a lower rate that the last. This gives consumers an inaccurate signal of the cost of service, and tends unduly to encourage consumption.

In concept, then, it would seem fairly simple to institute the rate reforms necessary to bring PREPA's rate structures into line with its cost structure. In practice, however, the case is not generally so clear as it might appear from this idealized discussion. This committee can recommend some basic reforms that would move rates in the direction suggested by a conceptual discussion of marginal costs, but most of PREPA's rate structures cannot be brought fully into line with its costs of service without much more precise information on how these costs vary with the amount of electricity consumed. PREPA is now analyzing its pattern of costs, under the mandate of the federal Public Utility Regulatory Policies Act of 1978 (P.L. 95-617). Its submission is due in November 1980, and presumably will serve as the basis for some changes in rate structures.

At present, however, it is clear that all declining block rates should be abandoned; set in the past as promotional devices, they can no longer be justified at today's rising fuel costs. Whether ascending block rates are justified, and what the appropriate structures should be for different classes of consumers,are questions that will be easier to answer when PREPA has completed its federally mandated cost-of-service analysis.

The Rate Structure

The Puerto Rican Electric Power Authority modified and simplified its rate structure in 1975-76, but the structure still contains many features that need refinement.

The Residential Subsidy

One of the most obvious features of the existing rate structure is the residential subsidy, available to residential consumers who use less than 425 kWh per month. A set of declining block base rates (Table 43) is established for residential use. These base rates reflect an oil price of $2.00 per barrel. Each unsubsidized residential consumer also pays a fuel cost adjustment charge reflecting the difference between the current price of oil and the $2.00 per barrel embodied in the base rate. For those who use fewer than 425 kilowatt-hour per month, this fuel adjustment charge is paid entirely out of Puerto Rican general funds, rather than by the consumer. The subsidy is available to any residential user, without regard to income or to whether the meter is for the principal place of residence.

As a practical result, this means that residential consumers using over 225 kWh per month pay 1.25¢ for each additional kilowatt-hour up to 425. The cost of the oil alone to provide each additional kilowatt-hour is roughly 5¢. Thus, residential rate structure gives an enormously inaccurate price signal, as a result of both the subsidized fuel clause and the underlying declining block nature of the rate.

Table 43 Existing residential rate structure for use less than 425 kilowatt-hours (kWh)[a]

4.50 cents per kWh for the first 75 kWh
3.00 cents per kWh for the next 75 kWh
2.50 cents per kWh for the next 75 kWh
1.25 cents per kWh for all use between 225 and 425 kWh

[a]All rates are subject to 11 percent surcharge.

structure. This subsidy is equivalent to providing each residential user with about 10 barrels of oil per year at a cost of $2.00 per barrel.

Although it is beyond the scope of this report to comment on the policy merits of the residential rate subsidies, it is clear that in Puerto Rico the subsidy presents a grossly inaccurate price incentive to conserve if the customer uses fewer than 425 kWh. (The figure of 425 kWh is found in the subsidy legislation and cannot be changed by action of the Electric Power Authority itself.) An analysis of the residential consumers subsidized indicates that many of them have electric water heaters and some have window air conditioners. (See Table 42.) There are probably other appliances the use of which is at least somewhat discretionary, but for all appliances substantial improvements in efficiency are achievable, and could be encouraged by revised residential rate structures. Chapter 7 points out that the subsidy effectively limits the introduction of solar water heating. From a distributional point of view, the primary impact of the residential subsidy may be not to favor low-income Puerto Ricans but rather to shift wealth from Puerto Rico to the OPEC nations.

Reform of this system deserves a high priority. We list below a number of possible steps to be taken to reform this rate structure. Some would require a revision in the underlying subsidy legislation. Not all are equally effective or efficient in correcting the underlying problem. Our choice would be to eliminate the subsidy completely and correspondingly increase general welfare payments to those in need, but the decision calls for expertise and information well beyond the boundary of our inquiry. Nevertheless, the impact of subsidizing oil use, as the current subsidy does, suggests the necessity for changes; better some gradual changes in the correct direction than no changes at all.

- Invert the base rate. One measure that could be taken without changing the underlying legislation would be simply to invert the base rate for electricity charges for small residential users, so that as consumption increases the price per kilowatt-hour rises also. Table 44 contains several hypothetical methods for doing this, setting out the total bills that consumers would receive. It must be emphasized, however, that these suggestions are only hypothetical. Bills paid by residential consumers would have to be analyzed to ensure that the Authority would not fall short in total revenue collected. The net impact of any such inversion would be to provide a considerable incentive to customers to begin conserving electricity sooner than they now do.

- Invert the rates and limit the subsidy by a means test. A further refinement of the reform suggested above would be to limit the subsidized rate to those who fall below some income level. It is beyond the charge of the committee to comment on how such a means test should be selected or administered.

Table 44 Hypothetical bill structures for the first 425 kilowatt-hours (kWh) residential rate[a]

Rate structure	kWh blocks	Number of customers	Cents per kWh	Customer bill	Total revenue raised
Present	0-75	115,733	4.50	$ 1.69	$3,211,833
	76-150	118,718	3.00	$ 4.50	
	151-225	97,625	2.50	$ 6.56	
	226-425	210,473	1.25	$ 8.75	
Variation one	0-75	115,733	2.00	$ 0.75	$3,481,256
	76-150	118,718	3.00	$ 2.63	
	151-225	97,625	4.50	$ 5.44	
	226-425	210,473	5.00	$12.13	
Variation two	0-75	115,733	4.50	$ 1.69	$4,187,567
	76-150	118,718	3.00	$ 4.50	
	151-225	97,625	4.00	$ 7.13	
	226-425	210,473	4.50	$13.13	
Variation three	0-75	115,733	1.25	$ 0.47	$3,362,474
	76-150	118,718	3.00	$ 2.06	
	151-225	97,625	4.75	$ 4.97	
	226-425	210,473	5.50	$12.25	
Variation four	0-75	115,733	2.50	$ 0.94	$3,860,474
	76-150	118,718	3.50	$ 3.19	
	151-225	97,625	5.00	$ 6.28	
	226-425	210,473	5.25	$13.12	

[a]Assumes: all users at the mid-point of each block; number of people in each block does not change with changed rate structure; total revenue should not fall from the class as a whole; very low kWh users should continue to have electricity provided below cost.

- Offer to subsidize solar hot water heaters instead of electricity. Since many of the residential users of electricity on the Island use the bulk of their electricity for heating water, the Authority might study the costs and benefits of offering those customers the opportunity to exchange the rate subsidy for a capital subsidy on the purchase of solar water heaters. The solar subsidy, whose source could be Puerto Rican general funds, would thus be turned to a domestic substitute for imported oil rather than to oil itself. Moreover, for the remaining portion of the bill, the residential consumer with the solar water heater would be confronted with the choice between consumption and conservation, and between using additional income on electricity or on some other good or service.

- Limit the subsidy to a smaller number of kilowatt-hours. By limiting the subsidy to a much lower figure the essential needs of consumers would be met with subsidized electricity, while more discretionary uses would not be subsidized. In July 1978, 43.3 percent of the residential customers used 225 kWh per month or less, while 70.8 percent used 425 kWh per month or less. Thus, a subsidy restricted to the first 225 kWh would reduce the number of customers receiving it by some 39 percent (before adjustments in consumption by those thereby withdrawn from the subsidy are taken into account).

- Put a cap on oil price rises that will be subsidized. With the present subsidy, each oil price rise automatically commits the Puerto Rican government to a larger subsidy. Puerto Rico, by legislation, might make oil price rises above a certain amount the responsibility of residential customers rather than of the government.

- Reduce the subsidy as consumption approaches 425 kWh. As the subsidy is now constituted, customers using 424 kWh per hour receive all of it, while those who use 426 kWh per month receive none. The subsidy might be redesigned so that it begins tapering off at, say, 250 kWh per month, reaching zero at 425 kWh. This would impose a gradually increasing cost pressure to conserve, replacing the current sharp ratchet effect felt all at once.

Rates for Industrial and Commercial Users

The rates for industrial and commercial users, like those charged residential consumers, reflect declining block structures. The justification for these declining block features is unclear; there appears to be no underlying cost-of-service analysis. It is likely that marginal energy costs are considerably higher than average energy costs. If so, declining block rates may well result at times in the sale of electricity to many large users for a price below the cost of the energy necessary to produce it. A full analysis of the extent of this phenomenon will require more data. A study of such declining block rates is mandated by the federal Public Utility Regulatory Policy Act of 1978.

We recommend generally the abolition of all declining block rate structures within a voltage level. Consideration should also be given to limiting the demand charge to actual peak hours on the system if it appears that the risk of outages is higher during such peak hours.

Customers might also be offered the option of paying for extra-reliable service, in the form of a surcharge that would be imposed only if the Electric Power Authority were able to hold interruptions to a given customer below a certain level over a certain time period. A corresponding discount could be offered to customers willing to have service interrupted on short notice. Various levels of surcharges and discounts should be proposed and discussed with large industrial and commercial users; the Puerto Rico Manufacturer's Association has expressed willingness to cooperate in such a survey. The feasibility of offering such special rates depends on the feasibility of wiring and relaying the system to allow interruption; probably this is economic only for the largest customers. As smaller users are considered for such quality-differentiated service, the complexity and cost of the additional distribution network necessary to allow such a system might not be justified; an overall improvement in reliability might be cheaper.

The Fuel Adjustment Clause

To provide the system with both the resources and the incentive to improve its fuel efficiency, the formula under which the fuel adjustment clause is calculated should be revised to allow the system to retain in a special fund 25 percent of any savings in the heat rate that brings average fuel consumption below 11,500 Btu per kilowatt-hour. The fund's purpose would be to improve maintenance and the quality of service. The Authority should not be penalized for heat rates above the level; to do so would be to deprive the system of the resources to provide the necessary additional maintenance at the very time when such resources were most needed.

The special heat rate fund would also operate to the customers' advantage. The system would be able to keep a percentage of the saving only when the heat rate improved, and 75 percent of any such savings would be returned to the customers in the form of a lower fuel adjustment charge.

Other Subjects for Further Study

- The costs of backup capacity. Either the Electric Power Authority or the Office of Energy should begin getting some estimate of the number and size of backup systems planned by various users on the Island. In addition, an analysis of the cost per kilowatt of capacity and the fuel cost impact of such backup systems should be undertaken. These analyses may reveal that it would be cheaper to improve the reliability of the current system even if it were necessary to add one more fairly small oil-fired base load unit than to allow unreliable service to force customers to bear the costs of the considerably more expensive backup capacity. The Puerto Rico Manufacturers' Association has suggested that it may be able to help in this study.

- Load shedding techniques. A feasibility study of various load shedding measures (including interruptible water heaters, interruptible air conditioners, and interruptible industrial processes) should be undertaken. It should be possible to obtain such a study in the form of proposals or sales materials from vendors of such equipment. Some such equipment can be interrupted by remote control devices and would not require substantial rewiring.

COGENERATION OF ELECTRICITY AND STEAM

Cogeneration is an arrangement of equipment so that both electricity and useful heat are produced from the same primary energy source. The advantage is that less fuel is consumed than if one facility were used to produce only electricity and another to produce only heat. Cogeneration has been practiced for years in many industrial plants and in a few utility central power stations. Rising fuel costs and increasing recognition of environmental concerns have increased the attractiveness of cogneration.

Industry

Much of the potential for cogeneration is found in industrial operations that consume large quantities of steam generated in boilers on-site. There are three common types of cogeneration facilities: (1) a boiler that produces steam at a much higher pressure than required for process use, so that an extraction or back-pressure turbine generator can be powered, with exhaust steam used for process heat; (2) a combustion turbine and waste heat boiler combined with a steam turbine and generator; and (3) a diesel engine driving a generator combined with a waste heat boiler. With the available technology only the first type can use coal rather than oil. Industrial cogeneration in existing plants almost always requires installing new facilities rather than retrofitting existing boilers, although it is sometimes possible to use existing boilers as backup steam suppliers.

Estimating the potential for industrial cogeneration in Puerto Rico with any precision is extremely difficult because the economic feasibility of each installation depends so heavily on individual circumstances (such as the volume, temperature, and pressure of the process steam; the temperature and pressure of steam from the boiler;

the fuel used for cogeneration; the fuel previously used to generate steam; the cost of firm power and of backup power; the investment required; the operating factor of the industrial plant; and any incentives provided by the government). Such a study, covering many plants, poses a very large task indeed. Nevertheless, a brief study commissioned by this committee cites a potential on the order of 81 megawatts of generating capacity. Of this, about 28 percent comes from petrochemical plants, and 25 percent each from refineries and sugar mills. Exploitation of this potential would save about 690,000 barrels of oil annually, or almost 3 percent of the oil consumed by the Electric Power Authority in 1978.[8]

Another form of industrial cogeneration is to supply process steam to industry from a utility central power station. A number of such systems have been operating on the mainland for many years; most involve only one or two large steam users, although several studies have examined the concept of clustering many industrial plants around a central power station. Such a configuration operates within several important constraints. First, the requirements for steam and electricity must be such that the system as a whole balances. Moreover, the central power station and the steam-consuming industry cannot be far apart, for steam cannot be shipped economically more than a few miles. But the most important constraint in such a project is the difficulty of coordinating the planning of the industrial plants and the electric power station, with their different planning horizons, organizations, and goals. PREPA should consider various configurations of cogeneration in its planning process. Long-range planning is necessary, since the full benefit of such cogeneration is hard to achieve unless the required amount and type of process steam is known at the time the central power station cycle is designed. To be sure, power stations can be retrofitted to supply some steam, and new power stations can be designed to supply unknown future steam demands, but either approach can very easily result in inefficiencies that more than eliminate any potential savings.

Resort Hotels

Industrial plants do not represent the only opportunities for cogeneration on the Island. The large resort hotels could also cogenerate. In fact, since each is self-contained and controlled by one owner, they combine both technical and institutional factors in an attractive package. Resort hotels currently consume each year 77,000 barrels of oil, plus electricity generated by burning another 420,000 barrels per year. In addition to the fuel conservation inherent in cogeneration, there is the possibility of further cost savings due to the replacement of No. 2 fuel oil with less expensive No. 6 oil.[9]

Electricity would come from a generator driven by a diesel engine. One configuration examined would constitute a total energy system, providing electricity along with hot and chilled water. This system would follow the electric load and would require an investment of a bit under $2,500 per guest room. Burning No. 6 fuel oil, it would pay for itself in about 6.3 years at 10 percent interest. If it must use No. 2 fuel oil, the payback period would be almost 13 years.

A second configuration for resort hotels is simpler. System B uses some of the existing equipment, tracking the thermal demand and selling all the electricity it generates to the grid. Fuel savings would be 1,500 Btu for each kilowatt-hour generated on site, the equivalent of 35 gallons per guest room per month. An investment of $530 per guest room would be required. The payback period would depend on the prices negotiated between the hotel and the buyer of the electricity.

Some 85 percent of the sites for this kind of cogeneration are located in the San Juan Metropolitan Area; the potential amounts to about 31 megawatts of generating capacity and oil savings of 137,000 barrels per year for System A, or 7.3 megawatts of capacity and 78,000 barrels per year for System B.

Incentives to Cogeneration

Various financial and regulatory incentives have been proposed to accelerate cogeneration, whether in industry or for resort hotels. Among those that seem most likely to have some significant impact are:

- Loan guarantees to reduce risk and lower the "hurdle rate" of return
- Backup power rates that reflect cost savings to the utility
- Reduction of local taxes
- Favored treatment or priority on fuel availability

We do not at this time recommend any of these incentives, but we do suggest detailed studies of several candidate sites. In addition to any incentives that may be provided, PREPA should actively seek customer participation in the development of whatever type of cogeneration may be appropriate in each case, as long as there are no adverse economic or environmental impacts and the prospect exists for a net conservation of fuel and capital resources.

NOTES

1. Richard H. Shackson. August 1979. Assessment of Opportunities for Conservation in the Transportation Sector and Strategies for Implementation. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Arlington, Va.: Mellon Institute-Energy Productivity Center.

2. Shackson, Assessment of Opportunities for Conservation (note 1), p. 19.

3. Puerto Rico Department of Transportation and Public Works. September 1976. Analisis del Problema de Estacionamente y su Posible Solucion en el Futuro--San Juan Antiguo. San Juan.

4. Shackson, Assessment of Opportunities for Conservation (note 1).

5. GKCO Consultants. October 1979. Energy Conservation Measures for Puerto Rico. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Washington, D.C.

6. GKCO Consultants, Energy Conservation Measures (note 5), p. 31.

7. GKCO Consultants, Energy Conservation Measures (note 5), p. 58.

8. Burns and Roe, Inc. September 1979. Industrial Electrical Cogeneration Potential in Puerto Rico. Report to the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council. Oradell, N.J. p. 17.

9. GKCO Consultants, Energy Conservation Measures (note 5), p. 39-55.

7 RENEWABLE ENERGY SOURCES

The dramatic rise in world oil prices since 1973 has opened up for serious consideration a new range of energy supply possibilities, many of which were until recently only scientific curiosities or of specialized practical interest. Each is intended to meet a different need, and each has its own developmental timetable. Some of those considered in this chapter are beginning to contribute now, and some will not be fully ready for several decades, if ever. All, however, hold enough potential benefit to Puerto Rico in the next 20 years to warrant close examination, and some deserve immediate measures to encourage use.

The alternative energy sources that this committee views as important candidates in Puerto Rico are (in order of probable significance during the next 20 years) biomass cropping for energy, solar water heating, hydroelectric power, wind-powered electricity generation, solar photovoltaic energy conversion, and ocean thermal energy conversion (OTEC). Puerto Rico is peculiarly favored for most of these alternatives. Sunshine is intense and consistent over most of the Island, the trade winds blow almost constantly, the climate is suitable for year-round cropping, and the large temperature gradient required by OTEC installations can be found in the waters relatively close to shore.

Of all the alternatives discussed in this chapter, biomass cropping, based on the present sugarcane industry, has probably the largest potential. It could produce a significant fraction of the Island's electricity, with bagasse as a fuel, by the year 2000. To contribute as much as 10 percent, however, it would probably have to become the Island's dominant agricultural activity. Such an industry, when mature, would probably produce both bagasse as a fuel for power plants and ethanol as a beverage and motor fuel. The technological problems are fairly straightforward, and the economics appear reasonably encouraging. The main difficulty is likely to be the competition for land with other agricultural products.

Solar water heating also offers significant potential savings of electricity and fuel in Puerto Rico. Its likely contribution by the year 2000 appears to be about 2 percent of total electricity generation (in terms of energy displaced), and almost 4 percent of industrial and commercial energy use. Collectors for the Puerto Rican climate could be simple and inexpensive compared to those that would be used in most other parts of the United States. Without government incentives to encourage installations, however, deployment will be slow.

The prospects for both wind energy and hydroelectric generation depend largely on the availability of useful sites. With the rapid increase in the marginal generating cost of new conventional power plants, a closer look at the potential for useful energy from these approaches is warranted. Hydroelectric generation now provides less than 1 percent of the Island's electricity; refurbishing and modifying existing reservoir sites could probably maintain this percentage contribution as the Island's total generation grows through the rest of the century. Wind power, by the end of the century, could contribute as much or somewhat more.

Solar photovoltaic generation of electricity will be successful only if the U.S. Department of Energy's cost reduction goals are achieved. This technology is unlikely to have a significant impact on the Puerto Rican energy situation until near the end of the century in any case. Progress in research and development should be monitored, however, because photovoltaic electricity may be very important in the next century, and photovoltaics manufacturing could be a very desirable industry for Puerto Rico.

Ocean thermal energy conversion (OTEC), a speculative technology intended to exploit the temperature difference between the surface and the deeper waters in the ocean, is considered a high-risk undertaking for a number of technical and economic reasons. Puerto Rico, however, has several ideal sites for OTEC power stations, and federal funds for demonstration plants should be aggressively pursued. This technology is unlikely to contribute significantly before the end of the century.

Tables 45 and 46 summarize this committee's assessments of the potential contributions of these technologies to Puerto Rico's energy supply over the coming 20 years. The estimates are the result of a tentative examination of the Puerto Rican situation, and the values in the tables should not be taken as predictions of the future. They merely indicate, in relative terms, the promise each technology appears to offer on the Island in this period, and suggest rough priorities. Several of these technologies are the subjects of active research and

Table 45 Potential contributions of renewable energy sources to Puerto Rico's electricity needs

Source	Annual production (billions of kilowatt-hours)[a]								
	1977	1990				2000			
		Optimistic projection		Planning expectation		Optimistic projection		Planning expectation	
Biomass-derived electricity	0	2.0	(10.4)	0.6	(3.2)	8.1	(30.0)	2.7	(9.9)
Residential solar water heating	0	0.19	(1.0)	0.11	(0.6)	0.55	(2.0)	0.29	(1.1)
Hydroelectric	0.10[b]	0.20	(1.0)	0.10	(0.6)	0.27	(1.0)	0.17	(0.6)
Wind	0	0.17	(0.8)	0.03	(0.2)	0.50	(1.8)	0.13	(0.5)
Photovoltaic[c]	0	0	(0)	0	(0)	0.02	(0.1)	0	(0)
Ocean thermal energy conversion	0	0.09	(0.5)	0	(0)	0.35	(1.3)	0.18	(0.6)
Projected total electricity production[d]	13.7	19.2				27.4			

[a]Parenthesized numbers indicate the percentage of total demand (based on the high estimates from Chapter 3) that could be met or displaced by each estimated contribution.

[b]0.7 percent of total electricity demand

[c]The contribution of photovoltaic devices is particularly sensitive to advances in research and development. Small-scale, dispersed systems, for example, could have large impacts, if successfully developed; see text.

[d]From Chapter 3's high growth projection (Case A).

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Table 46 Potential contributions of renewable energy sources to Puerto Rico's fuel needs

Source	Annual production (trillions of Btu)				
	1978	1990		2000	
		Optimistic projection	Planning expectation	Optimistic projection	Planning expectation
Solar water heating for industrial process heat[a]	0	3.13 (2.0)	1.71 (1.1)	7.87 (3.8)	4.86 (2.3)
Biomass-derived ethanol[b]	0	6.95 (10.2)	2.12 (3.1)	29.72 (40.7)	9.75 (13.4)

[a]Assumed to displace distillate fuel oil with a heat content of 5.8 million Btu per barrel. Parenthesized numbers indicate the percentage of industrial and commercial energy consumption displaced, in Chapter 3's Case A projection.

[b]Assumed to displace gasoline with a heat content of 5.25 million Btu per barrel. Parenthesized numbers indicate the percentage of total gasoline consumption displaced, in terms of Chapter 3's Case A projection (ignoring consumption by the rum industry).

development efforts, funded largely by the federal government. Unusually rapid technical advances or breakthroughs could permit higher rates of application than those tabulated here, and the Puerto Rican government should remain alert to such developments and take full advantage of them as they occur.

BIOMASS

The growing need for alternatives to oil has prompted examination of crops and crop residues as energy sources. In some circumstances such schemes appear very attractive.

Puerto Rico's dependence on increasingly costly oil helps create such a favorable circumstance. In addition, the production of sugar cane--one of the most efficient photosynthesizers--is well-established there, the climate is suitable for year-round energy cropping, and the Island has well-staffed centers for research in the agricultural aspects of biomass production, as well as advanced fermentation and distillation methods. Puerto Rico's potential as a biomass laboratory for the benefit of tropical countries around the world lends further importance to this alternative.

All in all, energy cropping may in the intermediate term be for Puerto Rico the most important renewable energy source. Given vigorous development, it might provide 10 percent or more of the Island's electricity by the year 2000. Ethanol produced as a coproduct could eliminate the Puerto Rican rum industry's dependence on imported molasses and also supplement gasoline supplies.

Energy Crops for Puerto Rico

The sugar industry on the Island now aims at maximizing sucrose production. This means that the cane must be grown on an annual cycle, with harvesting mainly in the spring, when sucrose levels are at their peak. In terms of energy yield, this produces annually on an Island-wide average about nine oven-dry tons of biomass per acre, or the equivalent of about 22 barrels of crude oil.[1] In the intensive cropping patterns that have been proposed for a sugar-cane-based biomass production industry, yields of fiber, rather than sucrose, would be maximized. Such management in test plots has increased biomass yields more than threefold, with production input increases of under 50 percent.[2,3] Harvesting would take place over an eight-month period.[4]

In a biomass enterprise, cultivating, harvesting, transporting, and processing the cane would consume energy. Energy balances for Puerto Rican biomass exploitation have been computed recently by the Center for Energy and Environment Research[5] and others.[6,7] These estimates suggest that the overall energy balance, from cane to either electricity or ethanol, should be about 2:1.

Emphasis on total fiber and fermentable solids (molasses) would appreciably lower the plant's sucrose content, but this would be partially countered by higher yields of D-fructose and D-glucose. In milling, the sucrose would be retained in the concentrated juice, offering alcohol producers a higher quality feedstock ("high-test" or "enriched" molasses) while reducing the energy expenditures of sugar milling and refining operations. A biomass enterprise could in this way eliminate the Puerto Rico rum industry's reliance on imported molasses. Surpluses could be used as gasoline additives or chemical feedstocks.

Using baseline data obtained under federal sponsorship, the Center for Energy and Environment Research (CEER) has developed a proposal for an industrial-scale demonstration model for year-round production of electricity, and eight-month production of high-test molasses, from biomass.[4] Essentially a modified sugar mill, the proposed facility would be a 1000-ton-per-day, 10 megawatt cogeneration plant using waste stack heat to improve the combustion properties of bagasse. The proposal was submitted to the Puerto Rican government late in 1979.

Cane Production, Processing, and Energy Conversion

Production costs for Puerto Rico were recently estimated in a technical report to the U.S. Department of Energy[2] at $25.46 per oven-dry ton of biomass, amounting to about $1.70 per million Btu. This figure includes delivery charges at $7.00 per ton for each three miles of haul. A "management" charge equal to 10 percent of the production cost subtotal was also listed.

The machinery for planting and harvesting would be relatively simple adaptations of available equipment. Throughout the world, such machinery is adapted locally to serve local needs anyway.[8]

The technology for using bagasse efficiently as an energy source, while it is not commercially available, should not present difficult engineering problems. Cane preparation and juice extraction would actually be simpler (and much less energy intensive) than the corresponding steps in sucrose manufacture. When the goal is to maximize total biomass, large juice yields are less critical. Perhaps 65-70 percent, rather than 85-90 percent, of the cane's sugar content would be extracted, and large savings in capital and energy costs would result. By-product heat and steam from the combustion facility could be used in this process.

The main technical problems are to devise equipment for putting the fuel in a form conducive to handling and combustion, and for efficient combustion of the resulting fuel. Most of the required equipment is not commercially available now. Because the bagasse is extremely low in both ash and sulfur content, waste disposal and pollution control costs would be minimal.

The ethanol phase of a sugarcane-based biomass scheme presents more problems and uncertainties (though, unlike bagasse, ethanol has a proven history of use as a fuel). Both fermentation and distillation of fuel-grade ethanol require a good deal of improvement in efficiency to bring costs down. The University of Puerto Rico's Agricultural Experiment Station has an effective and well-equipped Rum Pilot Plant, which until recently has served the needs of the Island's rum industry but is now turning to research in the production of fuels from sugar crops.

The Energy Potential of a Sugarcane-based Biomass Industry

The extent to which conventional sugarcane could help meet Puerto Rico's energy needs is uncertain. However, since 1978 there has been a growing body of data on the energy potential of sugarcane managed especially for energy.[10,11]

As measure for a possible upper limit for the year 2000, one investigator[12] indicates that if 270,000 acres of mechanizable land were devoted to sugarcane as an energy crop, it could produce about 235 million gallons of alcohol per year. This would be enough for both the rum industry's needs and a mixture of perhaps 20 percent ethanol in the Island's gasoline supplies. In addition, according to the same source, the bagasse remaining after extraction of the juices for ethanol production would be sufficient to produce 8.1 billion kilowatt-hours of electricity (about 30 percent of the Island's projected electricity demand). At $30 per barrel, the electricity production alone would save about $405 million annually.

This estimate is based on the assumption that the 90,000 acres of land now devoted to sugarcane cultivation would be trebled to include all of the improved mechanizable lands with adequate moisture or irrigation (30 percent of the available agricultural land on the Island). Obviously, dedicating so much of the available land to an energy crop will be controversial.

The committee considers this a very ambitious program. A biomass industry is likely to grow much more slowly than this, and in the committee's judgment will probably never attain the size given in this estimate of its potential. It is more reasonable (though still optimistic) to expect no more than 20 thousand acres in energy crops by the year 1990, even with very encouraging results from an early pilot project and a strong push thereafter. This could contribute about 600 million kilowatt-hours--something more than 3 percent of the projected electricity demand in that year--and perhaps 17 million gallons of alcohol. By the year 2000, given success with such a program, biomass crops might be expected to occupy perhaps 90 thousand acres, contributing 2.7 billion kilowatt-hours--about 10 percent of the projected electricity demand--and about 78 million gallons of ethanol. The electricity component, with oil at $30 per barrel, would save the Island about $130 million annually in external payments.

On the other hand, the establishment of a land use policy that emphasizes agriculture for food, coupled with discouraging results from a pilot-scale facility, may limit biomass cropping as an energy source to perhaps nothing more than a single pilot plant during the rest of this century.

Recommendations

The committee cannot, of course, predict the future of a Puerto Rican biomass energy industry, but in its judgment biomass cropping holds great promise. Though it is not likely to become the dominant energy source on the Island, it could be a very substantial contributor, as the estimates above indicate. The Puerto Rican government should investigate it very thoroughly.

In allocating the limited area of suitable land, the economic and social costs of importing oil must be weighed against those of importing food. A number of agronomic and technological questions must also be answered in assessing the realistic prospects for biomass energy development.

The allocation of land involves a decision clearly beyond this committee's charge. The technical and economic information that will put that decision on practical grounds, though, can be gained at fairly reasonable cost. The Puerto Rican government should engage a disinterested agricultural economist to analyze the current land use situation and the optimal future possibilities. Biomass cropping should be treated in this study as one option among the others.

To provide data for this study, a qualified engineering firm should be engaged to develop a plan for pilot-scale biomass production and conversion. This analysis should be complete enough to identify the technological problems and determine the likely costs and energy balances of a full-scale system. If the prospects are encouraging at this point, the Puerto Rican government should seriously consider establishing a pilot biomass-fired generating plant with a capacity of perhaps 10-20 megawatts. This plant should include all the elements that would make up a commercial system, including the intensively managed cane fields needed for year-round operation (about 1,750-3,500 acres, assuming a net dry biomass yield of 20 tons per acre).

At the same time, further funding of fermentation and distillation research at the Agricultural Experiment Station's Rum pilot plant should be aimed at more efficient, less costly methods of manufacturing fuel alcohol. This technology may eventually become important on the Island; it is already of great importance in some other countries.

SOLAR WATER HEATING

The use of solar energy for heating water is one of the most promising near term renewable sources of energy for Puerto Rico, offering substantial potential savings in electricity and thus reductions in the need for imported petroleum. The ample sunshine and temperatures that never go below freezing permit the use of simpler and less expensive collectors than those required in most areas of the mainland United States. The technology is well advanced, and commercially available systems can be substituted directly for electric and oil-fired systems in household, commercial, and industrial applications.

The Residential Sector

It is estimated that 3,000 residential solar water heating systems have been installed in Puerto Rico.[13] In addition, the Department of Defense has completed installation of 1,000 solar water heating systems in Navy housing at Roosevelt Roads and is planning to install another 3,000 units at various other installations on the Island. The extent to which solar systems can further penetrate the residential water heating market depends on the development of cost-competitive, reliable systems, the development of consumer confidence, and the degree of government intervention in the market. Manufacture and installation of solar hot water systems in Puerto Rico began in 1974 and has expanded to keep pace with local demand and exports to other Caribbean areas and Florida.

Information on the number of residences now equipped with electric water heating systems is very limited. It is also uncertain how many of the installed heaters are actually used. Estimates for 1977, based on Puerto Rico Electric Power Authority (PREPA) surveys, vary from about 365,000[14] to 479,000. The latter number is that used in the energy demand projections of Chapter 3, and will serve as the base for this chapter's assessment of the market for solar water heating systems. We shall assume, again with Chapter 3, that the number of residential water heaters grows at about 3 percent annually until the year 2000.

A survey by PREPA, performed in the San Juan metropolitan area from December 1977 to February 1978,[15] indicated on the basis of a small sample that the average residential consumption of electrical energy for water heating amounted to 200 kWh per month. If the number of heaters and average consumption were as assumed, domestic water heating would have accounted for about 10 percent of Puerto Rico's total electricity consumption in 1978.

Although solar water heating is the most competitive solar application on the basis of cost, the main barrier to widespread acceptance of this technology in the residential sector, as in all solar energy areas, is the high initial cost. In Puerto Rico an average solar water heating system suitable for a family of five cost approximately $1,000 in 1979, or about 3-5 times the cost of an equivalent electric unit. Using this as a reference point it may be helpful to consider the present situation of many Puerto Rican families.

A survey by PREPA[15] showed that more than half of its customers with electric hot water systems used fewer than 425 kWh per month and thus qualified for subsidized rates. For a family that stays just under the monthly limit of 425 kWh, the average cost of power would be about 2.7 cents per kWh. If this family consumed the assumed average quantity of 200 kWh per month for hot water, that service would cost $5.40 per month. At this rate such a family would never recover the $1,000 that a solar unit costs, assuming 10 percent financing over 10 years. In the absence of any other incentive there is obviously no reason for families in this category (70 percent of PREPA customers) to consider converting to solar.

Even the much higher electric power rates charged to unsubsidized customers give a fairly weak direct financial incentive. Unsubsidized customers pay about 6.8 cents per kilowatt-hour, based on August 1979 Electric Power Authority fuel charges of $19.10 per barrel. At this rate, an subsidized family would have to pay $13.60 per month for electric hot water service and could recover the cost of a solar unit in about 12 years (at 10 percent interest). Further increases in electricity rates resulting from continued increases in the cost of imported oil should increase the attractiveness of solar water heating to unsubsidized customers, but rates would have to more than double to bring the payback period down to a reasonable period, even for this minority of the population. (For a full discussion of the residential rate structure, see Chapter 6.)

Recent Puerto Rican legislation should offer considerable additional incentive to potential buyers of solar water heating systems by allowing 30 percent of the cost of these systems (up to a maximum of $500) to be deducted from taxable income[16] and exempting sales of these systems from the general 5 percent excise tax.[17] The current extraordinarily high interest rates are substantial deterrents to consumers; it may be desirable for the government also to consider special financing mechanisms to assist homeowners in purchasing and installing solar water heating equipment. Government consumer information programs and minimum quality and performance standards would bolster consumer confidence in solar water heating systems.

It appears from this rough analysis that solar water heating can capture a significant share of the residential market over the next 20 years. Government financial incentives and other measures to increase consumer acceptance will be necessary, though, for solar water heating to grow much in the near term. Given some such incentives, one might assume optimistically that between 1980 and 1985, 10 percent of the growth in water heating (as given in Chapter 3's high-growth

Case A) would be met by solar water heaters, and that this penetration would grow to 20 percent between 1985 and 1990 and 40 percent thereafter. One could assume further that 20 percent of the electric water heaters now existing would be replaced with solar heaters by the year 2000. Residential solar water heating could then displace about 1 percent of the projected electricity production (the equivalent of about 190 million kWh per year) by 1990 and 2 percent (about 550 million kWh) by the year 2000.

A more conservative basis for planning is provided by the assumptions that solar water heaters take 10 percent of the growth market up to 1990 and 20 percent thereafter, and that 10 percent of existing units are replaced with solar heaters by 2000. This yields the equivalent of about 110 million kWh in solar water heating by 1990 (about 0.6 percent of the projected electricity production) and 290 million kWh (about 1.1 percent) by the year 2000.

Solar water heating may be a very attractive option in the future, and might well capture larger percentages of the replacement market than those used in these projections. However, as noted earlier, the projections use as a baseline a number of existing water heaters that probably overstates the truth. The committee has therefore chosen a conservative estimate of the potential for retrofits, so that the estimated contributions of solar water heating in the residential market are probably of the correct orders of magnitude.

The Industrial and Commercial Sector

This committee has very little detailed information on industrial and commercial energy use in Puerto Rico--far too little for reliable estimates of the potential of solar water heating in these sectors on the Island. The Puerto Rican government would do well to look more closely at the characteristics of the Island's industrial base, and at the availability of land and roof area for solar installations.

However, on the basis of Chapter 3's energy projections it is possible to make some rough estimates. Taking the high projection in that chapter (Case A), and interpolating 1990 estimates of industrial and commercial energy consumption (excepting feedstocks), yields energy consumption totals for these sectors of 110 trillion Btu in 1977, 159 trillion Btu in 1990, and 210 trillion Btu in 2000. One can assume that 15 percent of the energy used in industrial and commercial establishments is used in quantities and at temperatures that would justify investment in solar heating systems. One may also assume that industrial and commercial establishments, accustomed as they are to life-cycle costing, will be readier than individual consumers to adopt solar heating.

Comparatively simple fixed flat plate solar collectors of the type presently used in solar water heating systems manufactured in Puerto Rico and in the mainland United States are adequate for relatively low temperature industrial applications used as domestic water heating and water preheating for a variety of manufacturing processes. More complicated solar thermal systems that concentrate the solar radiation are needed to provide the low temperature steam (approximately 250-400°F) used in food processing, pharmaceutical manufacture, and chemical processes. Savings in this temperature range are less evident than in the typical residential water heating temperatures, because the technology is less well developed and because of the competition of more conventional industrial conservation measures, as well as cogeneration.

Installations employing flat-plate collectors have been made in several industries to serve low-temperature applications. The largest of these is at the Johnson & Johnson Company in Las Piedras and is composed of 350 individual panels that produce domestic hot water at about 120°F, as well as preheated water for higher temperature applications. The India Beer brewery at Mayaguez has installed a small solar water heating system for evaluation purposes. The Nestle-Libby Company has submitted a proposal to the U.S. Department of Energy for a $2.3-million installation to provide water at temperatures up to 212°F, for use in food processing. The proposed system would use General Electric evacuated-tube collectors and would save an estimated 120,000 gallons of fuel oil annually.

Most opportunities for solar water heating in commercial and institutional establishments over the coming two decades would entail retrofits, because of the continuing lag in new construction. Solar water heating could supply much of the domestic hot water requirements of high rise buildings, restaurants, fast food stores, schools, and hospitals, but the expense of retrofitting installations will limit this market. Solar water heating systems now used in commercial and institutional buildings are estimated to displace only about 4 million kWh of electricity per year.

As in the residential sector, the recent Puerto Rican legislation to exempt solar water heating systems from the 5 percent excise tax should be a significant incentive for solar water heating in industrial, commercial, and institutional facilities. Likewise, this committee's recommendations of public information campaigns and government performance and quality guidelines would be as useful in the industrial and commercial sectors as in the residential sector.

Acceptance of this technology could be further encouraged by the Puerto Rican's government's installing and demonstrating solar water heating systems in more public buildings; an excellent example is a current plan to equip 70 public schools with solar heating systems.

An optimistic assumption would be that as energy use in the industrial and commercial sector grows, 25 percent of the growth in those applications suitable for solar systems (assumed to be 15 percent of industrial and commercial energy use) between now and 1990 will be served by solar installations, and 40 percent between 1990 and 2000. One can further assume that 20 percent of existing suitable applications will be served by retrofitted solar installations by 2000. This yields a contribution of 3.1 trillion Btu by 1990 (equivalent to about 2.0 percent of the projected industrial and commercial energy consumption in Chapter 3's Case A) and 7.9 trillion Btu (about 3.8 percent of projected consumption) in the year 2000.

Under the more conservative assumptions that only 15 percent of the suitable applications are served by solar facilities between now and 1990 and 30 percent thereafter, with 10 percent of current applications retrofitted, solar water heating in industry and commerce would displace about 1.7 trillion Btu in 1990 and about 4.9 trillion Btu in 2000 (about 2.3 percent of the projected energy consumption in these sectors).

Conclusions

This committee's assumptions suggest that solar water heating can displace perhaps 1 percent of the Island's projected electricity production by the year 2000, and about 2 percent of projected industrial and commercial fuel use, given the fairly modest incentives already enacted or contemplated by the Puerto Rican government. This would amount to annual oil savings of about 1 million barrels, or $30 million with oil at $30 per barrel.

This technology, given these incentives, appears marginally economic in Puerto Rico. Thus, its near-term contribution depends rather directly on Puerto Rican government policy. The direct and indirect incentives suggested in this discussion could tip the balance of consumer acceptance rather sharply, speeding deployment and thus increasing the cumulative contribution. Of all the technologies discussed in this chapter, solar water heating is the most directly amenable to such prompt policy action.

The government of Puerto Rico should therefore give high priority to the formulation of an appropriate program of financial and other incentives. Such an incentive program should be continually revised as the economics of solar water heating change in the coming decades. It would, of course, be ill-advised to pay too high a premium (in subsidies for solar systems) for savings in oil imports.

HYDROELECTRIC POWER

Most of Puerto Rico's rainfall occurs at high elevations and thus presents potential for hydroelectric generation. On the other hand, the small area of the Island makes for short rivers and thus limited numbers of sites. Many of the promising sites have already been exploited. Puerto Rico has 17 reservoirs, 13 of which are used to feed the various hydroelectric facilities. About 103 million kilowatt-hours of hydroelectric power, or less than 1 percent of total current electricity production, is generated annually.[18] This is less than half the peak hydroelectric production of the 1960s.[18,19] The PREPA attributes this decline to retirement or reduced operation of facilities that appeared uneconomic at pre-1974 oil prices, some system deterioration due to age and weather, variations in rainfall, and diversion of water for other purposes.[20]

Only one of the existing nonpower reservoirs (Patillas, built in 1914) is regarded as having the potential for cost-effective addition of hydroelectric capacity.[21,22] A recent study of this reservoir for the U.S. Department of Energy concluded that the addition of 400 kilowatts of year-round base-load hydroelectric capacity would be economically feasible.[23] Preliminary assessments indicate only minor environmental problems.

Potential new sites for additional hydroelectric capacity are being assessed as part of a comprehensive Island-wide water supply study by the U.S. Army Corps of Engineers.[19,24] The purpose is to serve long-term municipal, industrial, and agricultural water requirements, with electricity generation as a secondary benefit where it can be developed without affecting the primary requirements. Estimates of potential power from each site were derived from synthesized values for mean annual runoff, based on detailed hydrological studies conducted over the past decade by the Puerto Rico Aqueduct and Sewer Authority, the U.S. Geological Survey, and the U.S. Army Corps of Engineers. Measured stream flow data were available in many areas to verify the estimates. These studies do not include environmental assessments; which must be part of any detailed, final assessment.

Twenty-four possible new reservoir sites were evaluated for hydroelectric potential, but only five were identified as possibly cost effective based on a preliminary analysis using estimated 1978 cost data. The total maximum capacity of these five new sites was estimated at about 16 megawatts, with an estimated average annual output of 68 million kilowatt hours.[24]

Even if all the above-mentioned opportunities for new hydroelectric installations were taken advantage of, and the lost capacity in existing installations recovered, hydroelectric power's contribution, about 270 million kWh, would be only a little more than 1 percent of projected demand in the year 2000. Still, this would displace about 450,000 barrels of oil that would otherwise be burned to generate power; at $30 per barrel, this is almost $14 million.

That contribution should be considered the most optimistic possible outcome for hydroelectric power. A more reasonable expectation for planning purposes would be that only a fourth of the sites identified in the Corps of Engineers study prove suitable for power generation, and that only half of the lost capacity can be reactivated. This would provide perhaps 170 million kWh by the year 2000, with the possibility of hydroelectric capacity growing slowly afterwards, depending on the costs of the alternatives, until all suitable sites have been used.

To clarify that outlook, the Electric Power Authority recently initiated a study of the feasibility of reactivating some of the lost capacity. We recommend that in addition the conclusions of the Corps of Engineers be reviewed in light of recent increases in world oil cost.

WIND ENERGY

Although Puerto Rico apparently does not have any areas with exceptionally high average windspeeds, the Island does benefit from relatively consistent trade winds out of the northeast and as a consequence may offer a number of sites where electric power may be generated at competitive rates. A preliminary appraisal of the wind energy potential in Puerto Rico, made by the General Electric Company,[25] on the basis of basic meteorological data and without detailed site assessments, indicates that the wind could provide as much as 2 percent of Puerto Rico's power generation by the year 2000.

The very large machines on which production of this quantity of energy is dependent are not yet commercially available. Such machines are under development by the Department of Energy but thus far only one machine of this size (2 megawatts) has been constructed and is just completing operational testing at Boone, North Carolina. Three additional machines (2.5 megawatts) of a more advanced and potentially lower cost design are under construction, and these are scheduled to begin operation near Goldendale, Washington in 1980-81. (These machines have two-bladed propellers, 300 feet in diameter, mounted on 180-foot-tall towers.)

While actual costs remain to be determined, the U.S. Department of Energy estimates that, on the mainland United States, these 2.5 megawatt machines will cost about $3,400,000 each (in 1977 dollars) for the second prototype units (omitting nonrecurring costs associated with the first prototype unit) or $1,350 per kilowatt, including site preparation and installation. Costs are estimated to decrease by one-half for production runs of 100 or more, so that the hundredth unit after commercial manufacture has started is predicted to cost about $1,700,000 or $675 per kilowatt.[26]

Based on machine costs in this range, the General Electric study[25] performed for this committee, calculated electricity generating costs between 10¢ and 20¢ per kilowatt-hour at windspeeds of 12 miles per hour and an annual fixed charge rate of 18 percent.

There is very little detailed information on the magnitude and distribution of the winds in Puerto Rico. In assessing the wind energy resource it was necessary to make gross estimates of local values, using a topographical map and interpolating wind velocity values from upper air climatological data and surface data from three widely separated reporting stations.

The General Electric study[25] identified, at the higher elevations, 75 possible sites for the installation of one or more very large (2.5 megawatt) wind turbine generators similar to those now being developed in the U.S. Department of Energy wind energy program. All of these sites are on peaks or ridges with clear access to the prevailing northeasterly winds. A survey of available maps indicates that about half the sites appear to be close enough to existing roads to permit transport of heavy components to the construction sites. The other half would require special road construction. If all sites were used, perhaps 85 of the large machines could be accommodated by the 75 locations, for a total installed capacity of about 200 megawatts.

This assessment also identified the region adjacent to the northern coast and roughly bounded by 18° 15' N and 18° 30' N as an area with generally clear access to the prevailing winds. Although specific sites in this region were not identified, the study estimated that 20-50 of the 2.0 megawatt machines could potentially be placed throughout this large area, particularly in the less densely populated western portion. The islands of Vieques, Cordilleras, and Pineros were also identified in the study as offering potential additional sites for these large machines.

Smaller, 100-foot-tall machines, like the 200 kilowatt machine on the island of Culebra, may find application at sites where the larger turbines would not fit. They may prove useful, for example, as supplemental power units on large farms, powering irrigation and crop processing equipment. However, until more sophisticated siting studies are completed, it will be difficult to identify specific locations. It is plausible that as many as 50 of these machines might ultimately be used. A machine of this size is being offered commercially by at least one manufacturer.

A wide variety of smaller machines (in the 1-45 kilowatt range) is becoming available from commercial vendors. It is not possible to estimate the potential market for these smaller machines, although they might find application in the agricultural market. In any case, their use will likely be insignificant in terms of the Island's total electricity needs.

If the ultimate contributions estimated above for each of the machine sizes were realized, the total installed capacity would be slightly more than 300 megawatts, with the largest machines accounting for over 95 percent. Because winds are intermittent and variable, the average output of a wind turbine generator in Puerto Rico is generally about one-third that of a conventional plant with the same capacity rating. On the basis of the estimated average wind velocities and the operational characteristics of the machines, 300 megawatts of wind turbine capacity is estimated to produce about 500 million kWh annually. This energy output value is derived from data on existing turbine prototypes and designs, which in the cases of the larger machines were developed for average windspeeds greater than those in Puerto Rico. The result is lower output per unit of capacity than would likely be achieved with new designs more appropriate to Puerto Rican conditions.

This estimate is a small part of Puerto Rico's electric power needs--perhaps 2 percent of projected demand in the year 2000. However, the electric power thus produced would displace nearly 850,000 barrels of fuel oil per year, or $25.5 million with oil at $30 per barrel.

Site selection, installation, and testing for 250-300 megawatts of wind turbine capacity would take many years. The commercial availability of the machines will depend largely on the growth in demand for them throughout the United States. In an optimistic projection, one can assume that Puerto Rico will very soon install one or two machines of each size to gain procurement, installation, and operating experience before beginning a major acquisition program. Under this assumption, about one-third of the total potential capacity (producing about 170 million kWh per year) could be installed by 1990 and the remainder of the 300 megawatt capacity by the year 2000.

It is much more likely that these estimates will not be attained. Much detailed wind survey work must be accomplished to identify suitable sites. Then, sites must be acquired. Although wind technology has advanced greatly in recent years, there remain major uncertainties in machine reliability, installation and operating costs, and public acceptability. Because of these factors we believe that a more reasonable assumption is that Puerto Rico would procure and install one or two machines of each size for evaluation over two to three years. A limited acquisition program would then be initiated; small groups of machines would be bought and installed one after the other, so that machine performance and costs could be continually monitored and further acquisition plans modified as appropriate. On this basis it is estimated that about 6-8 machines could be installed by the year 2000. This would provide a total of 60-80 megawatts of installed capacity, or about 125 million kWh annually by the year 2000 (about 0.5 percent of projected power consumption).

It is the view of the committee that wind energy, even with its limited potential may be an attractive source of electric power and is worthy of further study by PREPA. The present very limited data base on the magnitude and distribution of the winds in Puerto Rico needs to be expanded. Potentially favorable sites should be specifically identified; then meteorological towers should be installed at the most promising sites to obtain wind velocity data at elevations appropriate to modern wind turbines.

Operational experience with the experimental machine on Culebra is encouraged. Similar machines are operating in Clayton, New Mexico, and Block Island, Rhode Island, and an additional machine is planned for installation on Oahu, Hawaii. The data gathered from these machines will provide valuable guidance for future decisions in this area.

PHOTOVOLTAIC ELECTRICITY GENERATION

Among the solar technologies being considered for use in Puerto Rico is the conversion of sunlight to electricity using photovoltaic cells. A typical photovoltaic energy system is composed of three major elements: a grouping of solar photovoltaic cells in an array or panel, an energy storage unit (such as a battery) and a power conditioning unit (or inverter). Sunlight striking the cells produces direct current which is converted to the alternating current required by most end uses.

In their simplest form, these systems have many advantages. They are entirely electronic and have no moving parts. They produce electrical energy at essentially constant voltage over very wide ranges of solar intensity and thus can deliver usable energy any time they are receiving sunlight, even during periods of cloud cover. (The amount of power is directly proportional to the amount of sunlight received.) They are quiet, reliable, and simple to operate and have little environmental impact apart from their land use. Like all other direct solar energy systems, they require auxiliary storage if the energy is to be used outside the daylight hours.

However, these systems presently are quite costly to produce and use. Most photovoltaic systems now on the market use expensive single-crystal silicon cells derived from spacecraft technology. Major efforts, largely supported by the government, are being pursued to develop mass production techniques to reduce costs. There is also an active research and development program to identify and develop promising alternative approaches with the aim of decreasing power costs. However, it is considered unlikely that this second generation technology will produce competitive energy systems for use in this century.

Costs for photovoltaic arrays are usually expressed in terms of dollars per peak watt of output. The cost of silicon cell arrays is currently about $10 per peak watt. Since the peak output for simple, flat-plate systems is reached only when the array is directly facing the sun (normally at noon), the average output is substantially less, even for the daylight hours, and output at night is of course zero. The ratio of average to peak output depends on latitude and climate; in Puerto Rico it is estimated at the unusually high figure of 25 percent, giving 6 kilowatt-hours per day[27] for each peak kilowatt of capacity. On that basis, the average annual output would be about 2,200 kWh (25 percent of 8,760 hours per year), compared with 5,000 to 6,000 kWh annually per kilowatt of conventional base load generating capacity. Moreover, since complete photovoltaic systems always include wiring and support structures and often batteries and power conditioning equipment, the system cost is generally estimated at about 1.5 to 2 times the array cost, making the comparison still less favorable at present cost levels.

Because the output of a photovoltaic system is intermittent, it cannot directly displace much conventional capacity. Its capital plus operating costs per kilowatt-hour therefore must be almost as low as the fuel cost alone of the conventional system for it to be competitive. With residual fuel oil at $30 per barrel, a simplified calculation indicates that grid-connected photovoltaic arrays would become economical if their cost could be brought below 46¢ per peak watt. The calculation is as follows: Assuming a heat rate of 10,500 Btu per kilowatt-hour and a heat content of 6.3 million Btu per barrel of residual fuel oil, each barrel would produce 600 kilowatt-hours, giving a fuel cost of 5¢ per kilowatt-hour. Assuming that each kilowatt of photovoltaic capacity yields 2,200 kWh per year, the annual fuel saving would come to $110. With a capital charge rate of 12 percent per year (covering depreciation over 20 years and annual interest at 10 percent), that would support a total capital cost of $917 per kilowatt. On the plausible hypothesis that the costs of the photovoltaic array amount to about half the total system costs (including an allowance for maintenance and operation), the photovoltaic array could then cost $458 per peak kilowatt, or 46¢ per peak watt.

The U.S. Department of Energy, in its cost reduction program, hopes to bring the array costs down from $10 to 50¢ per peak watt by 1986 (in terms of 1975 dollars) and to 30¢ per peak watt by 1990. Costs in the range of 10¢ to 20¢ per peak watt by the year 2000 represent a longer range goal.[27] Although substantial progress is being made, these numbers must still be regarded as aspirations rather than predictions.

Because of the high costs, the use of photovoltaic cells, except in spacecraft, specialty consumer products, and experimental and developmental demonstrations sponsored by the U.S. Department of Energy (DOE) and the Department of Defense, has thus far been limited to remote small power applications for telecommunication relays and repeaters, signal systems, and cathodic protection devices for pipelines.[28]

Since currently available fixed, flat-plate photovoltaic arrays convert only a small fraction (10-13 percent) of the sun's incident energy into electricity, the amount of sunlight received is critical to the output power. Most of the available systems are so-called nonconcentrating systems, composed of cells arranged in fixed flat-plate arrays. However, it is possible to increase the intensity of the incident sunlight by using concentrating mirrors or lenses and thus reducing the amount of expensive cell material per unit power output. In using concentrators, the focus is critical and the motion of the sun must be tracked; this increases the complexity and cost of the system. A further refinement to take advantage of heat produced in the cells by concentrators is possible. In this experimental design, coolant is circulated to the back of the cells to collect the by-product heat for use in space heating and hot water heating, or for other purposes. Concentrating designs may be necessary if photovoltaic cell material remains relatively expensive. However, if the cost goals can be achieved for this material, the simpler flat-plate systems will probably be more economical.

Based on an analysis commissioned for this study[27] the committee has identified two potential market areas in Puerto Rico; remote use (for small applications for which it is not economical to connect to the grid) and central utility applications (as replacements for conventional power plants). The second use would require much greater cost reductions than the first. In some countries there is a third potential application in regions not served by central electric power grids, but since Puerto Rico already has an Island-wide distribution system, this type of application is not relevant.

The potential of small dispersed systems for residences and other buildings, connected to the utility grid but without storage, was not considered in this analysis because of a lack of technical information. In principle, obviating the need for storage would yield a cheaper system. This type of application is receiving substantial attention in the federal photovoltaic development program, and its potential in Puerto Rico should be evaluated carefully.[29] For example, if 200,000 residences could be fitted with 2 kilowatt systems, and 5,000 businesses with 10 kilowatt systems, the annual energy contribution of such systems by the year 2000 would amount to almost 1 billion kWh (roughly 4 percent of the projected electricity generation in that year).

The remote-use market for photovoltaic systems represents applications supplying power to equipment not connected to the central electric grid. This category includes equipment for small, low-power communication and navigation equipment; irrigation pumping; and cathodic protection of various structures and equipment. Power requirements may vary from 1 to 300 watts, and the systems may include small batteries and inverters to provide regulated alternating or direct current to the loads. Photovoltaic energy systems for these types of applications compete with batteries, small motor-generator sets, and thermoelectric generators. Although these applications represent the earliest likely use of photovoltaics, with perhaps an appreciable dollar value, they form an insignificant fraction of Puerto Rico's energy needs.

The central utility market is more important. Because photovoltaic systems depend on sunshine for electrical power production, these systems have little potential as substitutes for essential base load generating capacity, which must be available 24 hours a day. However, if cost reduction goals are met, photovoltaic systems in the megawatt size range might become economically feasible in the mid-1990s for limited application in central utility systems as a way of saving oil. Given the likelihood of continuing rises in crude oil prices, it is quite possible that savings in fuel oil costs could repay the costs of the photovoltaic systems. Such systems would have little requirement for storage batteries as long as the total photovoltaic capacity were small in comparison to the overall PREPA generating capacity, so that the utility system could readily absorb variations in electric power production resulting from changes in sunshine intensity.

Integration of photovoltaic systems into the Puerto Rican utility system will depend on extended testing and successful demonstration of similar systems under the U.S. Department of Energy development program. If U.S. Department of Energy cost and performance goals are met, photovoltaic systems in the megawatt size range could become economically competitive in the early 1990's. In that case, Puerto Rico might initiate a limited acquisition program with the procurement in the mid-1990's of a relatively small system (on the order of 1 megawatt) for testing and evaluation over a period of about two years. PREPA then might procure an additional 10 megawatts of photovoltaic systems by the year 2000.

However, given the uncertain prospects of meeting the federal cost reduction goals, it would be wise to plan on the basis of at least a five year delay, so that large scale photovoltaic installations would not become commercially feasible until nearly 2000 at the earliest. It is unlikely in this case that photovoltaics would make any appreciable contribution to Puerto Rico's energy needs by the year 2000.

If, as, and when the major technical and economic breakthroughs take place, Puerto Rico offers unusually favorable conditions for their application. Technical progress should therefore be closely monitored, and Puerto Rico should participate in the U.S. Department of Energy's experimental program by pursuing federal research, development, and demonstration funds.

OCEAN THERMAL ENERGY CONVERSION

Ocean thermal energy conversion (OTEC) is one of the few renewable energy technologies that offer the promise of base-load capacity, on line 24 hours a day. This technology exploits the solar energy stored in the upper layers of tropical and sub-tropical ocean waters, where the temperature difference between the surface layers and the colder deep waters is great enough to promise economic energy production. If it can be developed, it may supply large amounts of electricity to many regions of the globe. Island economies such as Hawaii, Puerto Rico, the Virgin Islands, Guam, Micronesia, and America Samoa, which are almost completely dependent on imported oil for electric power, are candidates for application of this new energy resource. The OTEC concept is at an early stage of development and there is little information about its components, its operational characteristics or its maintainability.

OTEC must be regarded as an expensive and risky undertaking, perhaps the biggest gamble in solar power. With other forms of solar energy the uncertainties are mainly matters of whether cost goals can be met; with OTEC there is the distinct possibility that little or no net usable power may be produced. The temperature difference (about 20-22°C) between the surface and the deeper waters is so small that the expected net conversion efficiencies are on the order of 2 to 3 percent. (Conventional steam power plants operate on a temperature difference of 400-600°C, at efficiencies near 35 percent.)

At these low efficiencies, enormous amounts of water must be pumped over the facilities' heat exchangers to yield significant amounts of energy. The machinery for doing so must be extremely large, with its own energy requirements. It is estimated that about 25 percent of the gross electric power output of a working OTEC installation would be consumed by the plant itself; conventional power plants have parasitic power requirements of about 5 percent.[30]

Another important factor affecting the net operating efficiency of an OTEC plant is that the efficiencies of the heat exchangers are extremely sensitive to changes in the temperature difference and to any corrosion or fouling of the heat transfer surfaces. Any resulting degradation in system performance will disproportionately reduce the power output. Maintenance costs and down time to prevent and correct corrosion and fouling by marine organisms are likely to be much greater than in conventional power plants.

An active program to better appraise the OTEC concept, including construction of a small demonstration facility off Hawaii, is being funded by the U.S. Department of Energy. Puerto Rico appears to be a good candidate for an early demonstration site for this technology. It offers an excellent location on the southeast coast, where the necessary depths for a demonstration facility can be found only 2 to 3 miles offshore. It has a deep water port that can readily be adapted to serve as an operational and support base and an onshore terminus for the undersea cable that would tie an OTEC installation into the power grid. Puerto Rico has much to gain if the program proves successful, and should aggressively pursue federal funding for OTEC research, development, and demonstration.

The Puerto Rico Electric Power Authority, in a proposal to the U.S. Department of Energy, has offered a program for a 40 megawatt (electric) prototype unit consisting of four 10 megawatt modules to be operational by the year 1990. If this program (or its equivalent) is funded and successfully carried out, it might be expected to produce about 175 million kWh per year (something less than 1 percent of projected 1990 demand). In forming an optimistic estimate of OTEC's contribution, this committee assumed that the prototype would be successfully developed but at a pace somewhat slower than planned. On the assumption that two of the 10 megawatt modules would be operational by 1990, with full capacity being reached in the 1990s and further additions of 40 megawatts' capacity by the year 2000, total production would be about 350 million kWh per year by 2000.

A more reasonable expectation, for planning purposes, is that only one of the 10 megawatt modules of the prototype will be operational by 1990, with no reliable power output, and that it will be the turn of the century before all four modules are at full capacity. The output in this case would be 175 million kWh, or about 0.6 percent of the Island's projected electricity demand at that time; over the following 15 years OTEC capacity in that case might be expected to reach about 400-500 megawatts.

On the other hand, there is the possibility that OTEC will not be successfully developed at all, in which case the prototype will be abandoned as an OTEC demonstration.

NOTES

1. A. G. Alexander. March 1979. Sugar and Energy Attributes of the Genus Saccharum--An Overview. Paper presented to Symposium on Alternate Uses of Sugarcane for Development in Puerto Rico. San Juan: University of Puerto Rico.

2. A. G. Alexander, W. Allison, M. Garcia, A. Velez, G. Ramirez, T. L. Chu, and J. Velex-Santiago. December 1979. Production of Sugarcane and Tropical Grasses as a Renewable Energy Source. First and second quarterly reports to U.S. Department of Energy Fuels from Biomass Systems Branch (DE-AS05-78ET2001). Rio Piedras: University of Puerto Rico.

3. A. G. Alexander. November 1979. Biomass as a Source of Boiler Fuel and Molasses for Puerto Rico. Report to Technical Congress for the Investigation and Conservation of Energy Resources, El San Juan Hotel, San Juan.

4. Center for Energy and Environment Research. November 1979. Energy Cane Management for Molasses and Boiler Fuel. Proposal submitted to the Office of the Governor by the UPR Center for Energy and Environment Research. San Juan: University of Puerto Rico.

5. L. Smith. January 1980. Energy Analysis: Production of Sugar Cane in Puerto Rico for Energy and High-Test Molasses. Unpublished manuscript submitted to University of Puerto Rico Biomass Energy Program.

6. L. Smith, consulting economist. February 7, 1980. Personal communication to A. G. Alexander, Center for Energy and Environment Research, University of Puerto Rico.

7. C. S. Hopkinson and J. W. Day. 1980. Net Energy Analysis of Alcohol Production from Sugarcane. Science 207(January 18): 302-304.

8. B. J. Cochran and R. Ricaud. July 1979. The Potential of Producing and Harvesting Sugarcane and Sweet Sorgham as a Renewable Biomass Energy Resource. Washington, D.C.: U.S. Department of Energy (ORO-5373-T1).

9. Agriculture Experiment Station Rum Pilot Plant. March 1979. Ethanol As a Motor Fuel for Puerto Rico. Paper presented to Symposium on Alternative Uses of Sugarcane for Development in Puerto Rico. San Juan: University of Puerto Rico.

10. A. G. Alexander, Center for Energy and Environment Research, University of Puerto Rico. November 17, 1979. Personal communication to Hon. Jose E. Salichs, Presidente, Comision de Agricultura, Camara de Representantes.

11. G. Samuels. 1980. Land Use Analysis of Puerto Rico. Report to the University of Puerto Rico, Center for Energy and Environment. Winter Park, Fla.: Agricultural Research Associates.

12. G. Samuels. March 1979. Sugarcane in Food and Energy Crop Rotations in Puerto Rico. Paper presented to Symposium on Alternate Uses of Sugarcane for Development in Puerto Rico. San Juan: University of Puerto Rico.

13. Enrique Garcia Associates. September 1979. Impact of Solar Water Heaters on the Economy of Puerto Rico. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

14. Barton Associates. June 1978. Final report on the Economic Feasibility of Solar Cooling and the Manufacture of Solar Components in Puerto Rico. Prepared for Puerto Rico Industrial Development Company. San Juan: U.S. Department of Commerce (Grant 99-06-09393).

15. Donovan, Hamester, and Rattien, Inc. April 1979. Energy Data for Puerto Rico. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

16. Puerto Rico Law No. 185, July 26, 1979, provides that a person buying a solar water heating system can claim an income tax deduction of 30 percent of the cost, to a maximum of $500.

17. Puerto Rico Law No. 8, enacted September 25, 1979, exempts solar installations from the 5 percent excise tax.

18. Puerto Rico Water Resources Authority. October 1976 through December 1978. General Monthly Progress Reports. Production Division. San Juan.

19. U.S. Army Corps of Engineers. 1977. Ponce Regional Water Resources Management Study. Appendix D: Technical Appendix, Part VI (Hydroelectric Power Potential). Report prepared for the Jacksonville District and the Government of Puerto Rico. San Juan.

20. National Research Council. 1979. Interim Report of the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering. Washington, D.C.: National Research Council.

21. Jose Marina, Puerto Rico Water Resources Authority. July 23, 1979. Personal communication.

22. Jose Martines, Planning Group, U.S. Army Corps of Engineers. July 23, 1979. Personal communication.

23. Energy Research and Applications, Inc. February 1979. Feasibility Determination of Hydroelectric Power Generation at Patillas Reservoir, Puerto Rico. Washington, D.C.: U.S. Department of Energy. (Agreement EW-78-F-07-1804).

24. Black and Veatch, Consulting Engineers. August 1978. Assessment of Hydroelectric Power Generating Potential Under the Island-Wide Water Supply Study, Phase II-B, Commonwealth of Puerto Rico. Prepared for the U.S. Army Engineer District, Jacksonville, Department of the Army. Kansas City, Mo. (Project No. 81165)

25. General Electric Company. September 1979. A Wind Energy Assessment for the Commonwealth of Puerto Rico. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

26. J. E. Eamler and R. M. Donovan. June 1979. Wind Turbines for Electric Utilities: Development Status and Economics. Paper presented at Terrestrial Energy Systems Conference, Orlando, Fl. Washington, D.C.: U.S. Department of Energy (DOE/NASA/1028-79-23, NASA TM-79170).

27. Solarex Corporation. August 1979. Final Report: An Assessment of Photovoltaic Potential in Puerto Rico: From Now Until the Year 2000. Report prepared for the Committee on Future Energy Alternatives for Puerto Rico, Energy Engineering Board, Assembly of Engineering, National Research Council.

28. U.S. Department of Energy. April 1979. Preliminary report: Export Potential for Photovoltaic Systems. Assistant Secretary for Conservation and Solar Applications. Washington, D.C. (DOE/CS-0078).

29. For details of this approach, and an overview of the federal photovoltaic program, see Division of Solar Technology. June 6, 1979. National Photovoltaic Program, Multi-Year Program Plan (draft). Washington, D.C.: U.S. Department of Energy (DOE/ET-0105-6).

30. U.S. Department of Energy. February 1978. Solar Energy Research and Development: Program Balance. Solar Working Group. Annex Vol. 2. Washington, D.C. (HCP/M2693-02, EA-77-C-01-2693).

APPENDIX A:

CONTRIBUTORS AND CONSULTANTS

BURNS & ROE, INC., Oradell, New Jersey

KEITH CHAPMAN, Consultant, University of Aberdeen, Scotland

DONOVAN, HAMESTER & RATTIEN, INC., Washington, D.C.

ANDRES DOERNBERG, Consultant, Mt. Sinai, New York

JORGE FREYRE, Economic Consultant, Guaynabo, Puerto Rico

ENRIQUE GARCIA ASSOCIATES, San Juan, Puerto Rico

GENERAL ELECTRIC CORPORATION, King of Prussia Park, Pennsylvania

GKCO CONSULTANTS, Washington, D.C.

PHILIP J. MAUSE, Attorney at Law, Kadison, Pfaelzer, Woodward, Quinn and Rossi, Washington, D.C.

MELLON INSTITUTE-ENERGY PRODUCTIVITY CENTER, Arlington, Virginia

HARVEY MORRIS ASSOCIATES, Lynhurst, New Jersey

NORMAN RASK, Consultant, Ohio State University

RICHARD ROSEN, Consultant, Boston, Massachusetts

SOLAREX CORPORATION, Rockville, Maryland

ROBERT SPENCER, Consultant, Lakeland, Florida