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BROOKHAVEN NATIONAL LABORATORY REGIONAL ENERGY STUDIES PROGRAM

ANNUAL REPORT FOR FISCAL YEAR 1976

MASTER

December 1976

POLICY ANALYSIS DIVISION
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

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BROOKHAVEN NATIONAL LABORATORY REGIONAL ENERGY STUDIES PROGRAM

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(JULY 1975 - SEPTEMBER 1976)

PETER M. MEIER, Editor

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POLICY ANALYSIS DIVISION
NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS
BROOKHAVEN NATIONAL LABORATORY
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PREFACE

The BNL Regional Energy Studies Program is a multidisciplinary effort involving personnel from a number of groups at the Brookhaven National Laboratory most of which are in the Department of Applied Science. In addition, a number of groups and individual faculty members at universities in the Northeast are collaborating in the program.

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TABLE OF CONTENTS

ABSTRACT

This is the second annual report for the BNL Regional Studies Program, covering the period July 1975 to September 1976. This program is part of a national effort supported by the U.S. Energy Research and Development Administration (ERDA) to create an energy assessment capability which is sensitive to regional conditions, perceptions, and impacts. Within ERDA, this program is supported by the Division of Technology Overview and includes, in addition to a concern for health and environmental impacts of energy systems, analysis of the complex trade-offs between economics, environmental quality, technical considerations, national security, social impacts, and institutional questions. The Brookhaven Program focuses on the Northeast including the New England states, New York, Pennsylvania, New Jersey, Maryland, Delaware, and the District of Columbia. The content of the program is determined through an identification of the major energy planning issues of the region in consultation with state and regional agencies. A major component of the program in 1976 was the Northeast Energy Perspectives Study which examined the implication of alternative energy supply-demand possibilities for the region. In 1977 a major component is the northeast portion of the National Coal Utilization Assessment carried out in collaboration with several other laboratories in other regions of the United States.

I. INTRODUCTION

The Brookhaven National Laboratory Regional Energy Studies Program is part of a national effort supported by the U.S. Energy Research and Development Administration (ERDA) to provide a solid basis for examining the implications of alternative energy futures for the nation. Until recently, most energy policy analysis and planning was carried out with a national perspective. Such analysis, however, is insensitive to the vast differences in character, from an energy point of view, of the various regions of the country. The intent of the ERDA Regional Studies Program is to create an energy assessment capability which is cognizant of and sensitive to regional conditions, perceptions and impacts. Within ERDA, this program is supported by the Division of Technology Overview under the Assistant Administrator for Environmental Safety, and, thus, has a particular concern for the health and environmental impacts of energy systems. But it is recognized that these impacts must be viewed in a broader context of the complex trade-offs between economics, environmental quality, technical considerations, national security, social impacts, and institutional questions.

The Brookhaven Regional Energy Studies Program focuses on the Northeast, including the New England states, New York, Pennsylvania, New Jersey, Maryland, Delaware, and the District of Columbia. The content of the program is determined through an identification of the major energy planning issues of the region and those national energy policy issues that require a regional scale of analysis. The intent is to assemble a set of data and analytical tools that can be used either at Brookhaven or by state and regional energy planning groups or collaboratively to analyze the social, economic, and environmental impacts of specific alternative energy strategies. At the same time, this resource and the specific regional analyses carried out will provide a significant contribution to national energy planning. Toward that end, the related programs at the other ERDA laboratories* have been structured and are being carried out in collaboration with the Brookhaven program.

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*Associated programs are underway at the Argonne National Laboratory, the Oak Ridge National Laboratory, the Lawrence Berkeley Laboratory, the Lawrence Livermore Laboratory, the Los Alamos Scientific Laboratory, and the Pacific Northwest Laboratory.

The program contains within it no preconceptions about the desirability of any particular level of energy use, any particular energy source or any particular energy policy. It is based on a basic premise that careful, objective analysis carried out with a regional perspective can make an important contribution to wise decisions on energy matters taken at the state, regional, or federal level. For example, if we study the increased use of coal in the Northeast, we do so in order to understand more fully all the advantages and disadvantages of that policy under various conditions of energy growth, environmental regulation, and incorporation of new technology.

The current activities in the Brookhaven program are structured into six major areas:

1. A Regional Framework for Energy Planning (Section IV) -- This area includes the construction of a region-wide set of data on environmental quality, socio-economic information and energy supply and demand; the development of assessment models; and studies of institutional mechanisms for energy planning at the state or regional scale (Section III). The Northeast Perspectives Study (Section II), a special study completed in mid-1976 addressed to the Energy Planning Problems of the Northeast, represents the principal effort of the Regional Studies Program in FY 1976.
2. Regional Energy Conservation Strategies (Section V) -- including an evaluation of the degree of implementation expected for particular conservation strategies, the energy system impacts and the legislative and institutional mechanisms required to implement them.
3. Methods and Issues in Energy Facility Siting (Section VI)-This area includes both the development of siting methodologies appropriate to regional scale analysis and the analysis of facility siting aspects of Northeastern energy policy.
4. Studies of Urban Energy Systems (Section VII), in the recognition of the predominance of large urban areas in the Northeast, and the special relationships between energy systems, the urban economy, and urban environmental quality.

Studies of the Use of Coal in the Northeast (Section VIII) -- This area includes the development of air pollutant transport models and health and environmental impact models that can be used to analyze the impacts of alternative coal utilization strategies; and the analysis of technical means of using coal as a function of time into the future and the physical constraints on such use. In 1977 and 1978 there will be a heavy emphasis on coal use as part of the National Coal Utilization Assessment, a co-ordinated study of all of the national laboratories' Regional Studies Program.

6. Studies of off-shore issues (Section IX) including the study of policy and environmental options associated with offshore energy facility siting, and oil and gas development on the Outer Continental Shelf. Some emphasis is also addressed to the development of mathematical models for use in the environmental assessment of offshore development.

This report is intended to serve a number of functions including communication with our colleagues and collaborators throughout the country, and with our sponsors in Washington. Most importantly, however, it is designed to be one element in a continuing dialogue with local, state, and regional bodies in the Northeast whose needs are a primary concern of this program. We consider that dialogue to be of great importance and are devoting considerable effort to a mechanism for facilitating it. Central to that mechanism is the Northeast Energy Perspectives Study, the subject of the next section.

II. THE NORTHEAST ENERGY PERSPECTIVE STUDY

(J. Brainard, D. Goettle, H. Davitian, P.F. Palmedo)

2.1 Background and Study Approach

With the passing of the crisis atmosphere produced by the 1973-74 oil shortage, concern over energy supply at a state level in the Northeast has diminished considerably. As a result, few of the states in the Northeast have developed coherent plans to analyze their energy options or even to forecast their future energy demands. In part, this lack of commitment has stemmed from the change in administrations in many of the states that took place in January of 1976. It may also result from a lack of perception of the consequences to the Northeast that will accompany a continuation of a present policy of "muddling through". Moreover, very few individuals in a position to make policy seem to be aware of either the implications of current and projected federal efforts or trends in the energy policies of the energy exporting states of the U.S. At the same time, circumstances--or political pressures--are forcing decisions in particular areas, for example relative to nuclear power and offshore oil. These decisions are of necessity being made with inadequate consideration of alternatives and implications.

Given this rapid deterioration of the Northeastern Energy Situation, the Regional Studies Program conducted a special study (The Northeast Energy Perspectives Study) addressed to a clear identification and clarification of the major energy issues of the region in the context of their relationship to energy planning and energy decisions made in other regions of the country, at the Federal level, and in other countries (particularly Western Europe, Japan, Canada, and the OPEC Nations). The component parts of the study deal in some detail with the economic, social and political consequences of decisions or lack of decisions. Thus, the central thrust was to outline the character of possible solutions, and to distill the salient features of the Northeastern energy system in terms of common interests of the Northeastern States.

A scenario approach was used as the central integrating mechanism for the study. Separate studies were carried out of all pertinent supply sectors: coal, oil, natural gas, liquefied natural gas, nuclear power, municipal waste, solar energy, and wind power. In each case a range of estimates of supplies to the Northeast was constructed, reflecting possible policy and technological developments and also the basic uncertainties of all such projections. Similarly, on the demand side, ranges of future regional energy demands were constructed representing, among other things, various levels of energy conservation practices in specific uses of energy.

We then constructed scenarios which matched possible regional demands for various fuels with their supplies. It was assumed that a shortage of liquid supplies from the U.S. would be made up by imports. A set of environmental coefficients (e.g., emissions into air and water) was assigned to each fuel-specific energy use so that a rough indication of environmental impacts could be derived for each supply-demand scenario. A number of scenarios based on alternative supply and demand assumptions could then be used to examine particular issues such as oil import reduction, offshore oil development, or nuclear power curtailment. It should be emphasized that the study did not deal with short-term energy supply problems, nor did it deal directly with the complex feedback relationships between energy prices, industrial activity, consumer demand, and employment.

In addition to the main report of this study, a number of supporting issue papers* were prepared by Brookhaven National Laboratory staff and collaborators from other institutions. Drafts of these issue papers which address specific energy supply or demand topics, and a draft of the main report, served as a basis for discussion at the Northeast Energy Perspectives Meeting held at Brookhaven on March 16 and 17, 1976, attended by over 150 participants from local, state and regional agencies, electric utilities and industry, citizen and environmental groups and the press.

2.2 Scenario Analysis

The results of the scenario analysis can be briefly summarized as follows:

*These are listed in the Appendix.

The Reference Scenario:

Current energy consumption in the Northeast (as fuels, including electricity) is about 12.3 quads (quadrillion or 10^{15} Btu). This requires the use of some 15.8 quads of basic energy resources.

A continuation of current trends in population, economic growth, and energy use patterns and of current policies related to energy resource development and usage would lead to an 80% increase in the demand for fuels in the Northeast and a 100% increase in energy resource requirements between 1972 and 2000. The need for imported oil would increase by 85%. Coal and nuclear power would each supply roughly 20 to 25% of the total resources used by the Northeast in 2000 (See Figure 1.)

Energy Conservation:

Conservation can play a major role in reducing the fuel and resource requirements of the Northeast: the moderate-conservation actions considered in our main report[1] can reduce fuel demands by 11% in 1985 and 18% in 2000 from the levels in the reference scenario, and the strong-conservation actions can reduce them by 19% in 1985 and 32% in 2000. Most of the measures that comprise the conservation strategies can be enacted or implemented at the State or local level.

The reduction in energy requirements resulting from conservation would have four broad effects in the Northeast: (1) It would make the Northeast less vulnerable to supply constraints and production bottlenecks and provide more options for dealing with them. (2) The substitution of devices and procedures consuming less energy would result in net long-run monetary savings. (3) Conservation strategies have a potential for creating more jobs within the region than corresponding supply strategies. (4) Environmental and health benefits would be derived from the lower levels of resource extraction and energy use both within the region and outside it.

Imported Oil:

Imported oil is likely to continue to play a major role as an energy resource for the Northeast. The reference scenario, based on the assumption

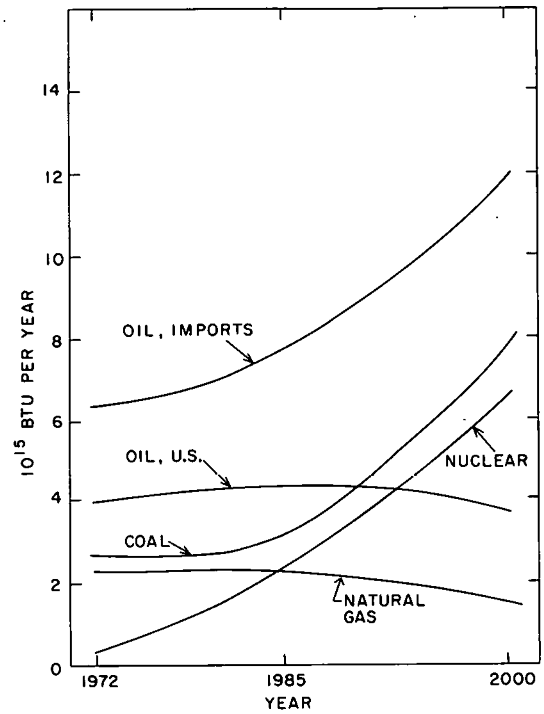

Figure 1. Resource requirements in reference scenario (scenario 1).

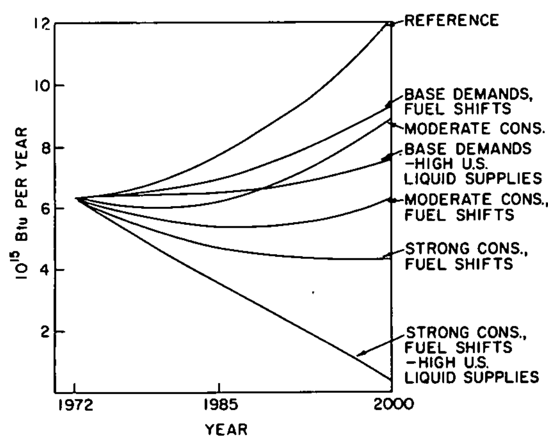

Figure 2. Oil imports to region (intermediate liquid supplies assumed except as indicated).

that no new policy initiatives are undertaken to affect supply or demand, projects an increase in imported oil requirements from 1972 level of 6.5 quads, to 12 quads in 2000. This corresponds to a change in the fraction of oil that is imported from 61% to 77%.

If a vigorous U.S. effort were mounted to produce synthetic liquids from coal and to develop oil shale resources and enhanced recovery techniques for conventional crude oil, and if this were coupled with higher than expected crude oil discoveries, the need for imported oil in the region could be reduced by nearly 4 quads. For a variety of reasons, a liquid fuel supply augmentation of this magnitude appears problematic.

On the demand side, moderate conservation could reduce the need for imports by about 2 quads and strong conservation by about 4 quads from the reference level (assuming constant supplies of other liquid fuels to the region).

If an effort is made to shift some of the demand from oil to electricity and low-Btu gas (produced from coal) and moderate conservation is invoked, import requirements for 1985 and 2000 could be maintained at approximately the 1972 level. Trends in oil imports implied by a number of the scenarios considered in the main report are shown in Figure 2. It is clear that a significant reduction in the level of imports, if it is deemed desirable and if it is to be achieved voluntarily and gradually, can be brought about only through early, concerted action at both the Federal and the local level.

Offshore Oil and Gas:

Estimates of the quantities of crude oil and natural gas recoverable from fields in the Atlantic Outer Continental Shelf are highly speculative and uncertain because of the lack of exploratory drilling to date. Current resource estimates suggest that in 2000 the maximum likely production rates would be 0.86 quads/year of oil and 0.56 quads/year of gas. The sum of these, 1.4 quads/year, amounts to 6% of the total fuels required for the region in the year 2000 in the reference scenario. Gas production of 0.56

quads/year, however, amounts to 20% of the reference case gas demand in 2000 so that, if this production rate were achieved and the gas were consumed totally in the Northeast, the offshore resources could provide a substantial fraction of the region's gas needs for two to three decades.

Nuclear Curtailment:

In the reference scenario nuclear power is projected to supply 6.5 quads of energy input to electricity production in 2000. In the low nuclear supply case, which would reflect a public decision to curtail the use of nuclear power, we assumed that no new construction is initiated after 1977 but that plants in operation or under construction at that time are unaffected. This would freeze the energy supplied by nuclear power at a level of 2.2 quads/year. If coal alone were employed to make up for the reduction in use of nuclear resources, the increased coal requirements would be 60% above the intermediate regional coal supply projection for 2000. Unless strict emission standards were met, such high coal use could result in a large number of deaths attributable to an increase in air pollution.

With moderate-conservation demand levels, nuclear power would provide 4.5 quads/year in 2000 without curtailment. The decrease to the 2.2 quad level under curtailment could be made up by the substitution of coal, raising the required regional coal supply level to less than 20% above the intermediate level. Alternatively, moderate conservation coupled with vigorous implementation of the use of wind power and solid waste for generating electricity could completely compensate for the decreased nuclear output. We did not consider all the possible substitutes for nuclear power. In particular, oil, either imported or produced synthetically, could be used to compensate at least in part for a reduction in nuclear power. However, such a shift to oil would raise the level of imports or production levels of synthetics above the already high levels in the reference scenario. Also, if the substitutes for nuclear power are higher in cost, the total cost to the region could be very high (in terms of both electricity prices and reduced economic growth).

New Resource Technologies:

Three new energy resource technologies can play a role in the Northeast by 2000: solar energy for heating and cooling; wind power; and the conversion of solid waste to electricity and gas. None of these technologies is impeded by significant technological barriers, but all are affected by institutional constraints. Waste conversion is economically competitive today under some circumstances, but this resource is limited to a relatively minor role (approximately 0.2 quads of electricity and 0.02 quads of gas) because of limitations on the availability and collection of wastes and refuse. The most rapid rate of introduction of solar energy systems considered in this study assumes that solar systems would supply 25% of the energy required for space heating and 70% of that for water heating in buildings constructed after 1985. Such use of solar systems would result in a 20% reduction in conventional fuel requirements in the residential and commercial sector by 2000, which is equivalent to 6% of the total fuels projected to be required in that year.

Wind power could also contribute materially to the fuel supply of the Northeast by 2000. Wind is abundant and the technology for its utilization is highly advanced. Although some cost estimates are encouraging, the economic viability of wind power as a major component of utility systems is still uncertain. The eventual level of implementation will depend also on public reaction to the visual impact of large windmills. In the intermediate wind power projection constructed for this study, it was assumed that wind power would provide 0.13 quads of electricity in 2000, about 4 to 5% of the electricity demand in that year, corresponding to about 1.5% of the resource requirement in the reference scenario. This would require approximately 6500 windmills of 1.5-MW rated capacity each.

Although the production of low-Btu gas in the region from coal was not projected to supply more than one quad of energy by 2000, it is a technology with a number of potentially beneficial features to the Northeast and deserves more serious study.

The Possibility of Lower U.S. Supplies:

Constraints on the supplies of U.S. oil and natural gas to the Northeast, reflecting a combination of lower than expected discoveries and a lower fractional allocation of the total U.S. production to the ortheast would, under the assumptions of the perspective study, reduce the total supplies of these resources to the region in 2000 to approximately half the levels projected in the reference case. What the future supply of natural gas will be is particularly unclear because of regulatory uncertainties that will affect future prices, the production levels at those prices, and regional allocations. In the low-supply case used in the study, natural gas supply to the region drops from the current 2.3 quads to 0.3 quads in 2000.

These reductions in availability of resources could be compensated for only by significantly higher use of coal (by a factor of 2) or by strong conservation and fuel shifts on the demand side. The region clearly has a vital interest in assuring the adequate development of U.S. resources.

2.3 Future Extensions

Although the perspectives study as outlined above has been completed and published, much work remains to extend the analysis to more detailed assessment of environmental and economic impacts. Thus in several areas the work plan for the regional studies program in the current year builds upon the perspectives study as a basis for relating energy system futures to environmental and economic impacts. For example, we have started an assessment of the environmental impacts of alternative oil supply scenarios, comparing the impacts of OCS development with the impacts of oil importation by tanker (See Section 9.3 below); an assessment of the air quality and health impacts planned as part of the National Coal Utilization Assessment (Section 8.4 below) relates directly to the coal supply policy scenarios analyzed in the Perspectives Study Coal Issue paper, and work discussed in Section 4.2 has the intent of relating energy systems to the regional economy, thus permitting a more detailed assessment of the regional economic consequences of alternative energy policy postures.

III. USER LIASON AND INSTITUTIONAL ANALYSIS

(S. Munson)

Energy problems can be thought as having two geographical scales: the political and the phenomenological. Decisions made in a legislative or executive context are dominated by political geography--the geography of the locality, the state, or the Nation. The phenomonological scale of energy, on the other hand, is determined by physical and technical factors such as the areal distribution of energy resources, the configuration of air quality regions and river basins, the range of transport of pollutants, the distribution of population, the existence of transportation and transmission grids, and the operation of regional power systems.

Although energy phenomena are manifest at the regional scale there are virtually no political institutions that operate effectively at this scale: decisions are taken in the existing geopolitical context. National policies are of necessity made at too large a scale to deal adequately with the tradeoffs between economic, environmental and social factors which must be considered in effecting decisions at the state or local level. On the other hand, state analysis and policy are often developed independent of regional or national implications. As a result, the phenomenological scale of energy systems receives short shrift when developing energy policy.

One important goal of the Regional Energy Studies Program is to circumvent the problems of scale (geopolitical and phenomenological) by developing analysis at the regional level and then translating the information to the levels at which decisions are made. The latter is accomplished by our program of Liason with the user community (Section 3.1); the former by a series of studies on the institutional and decision making framework.

3.1 User Liaison

There are two immediate goals of the liaison effort of the program. The first is to provide for the exchange of information, cooperation and coordination in ongoing policy research, and model and data base development. The second goal is to make research and tools developed by the RESP available and useful to potntial user groups. These would include federal, state and local executive agencies, regional commissions, private and incorporated planning and analysis groups, and special interest groups.

There are many types of contact between the program, its members and outside groups. In essence these can be summarized as follows:

Formal, Contractual Relationships: This category involves work performed under contract to BNL (and funded by the RESP) by outside groups, primarily by University Groups. Over the past year such contracts have included efforts at Cornell, The State University of New York at Stony Brook, M.I.T., Yale, Princeton, Carnegie-Mellon, the University of Pennsylvania, Johns Hopkins, the University of Tennessee, and Queens College, City University of New York.

Formal, Cooperative Relationships

Many parts of the RESP involve cooperative work with outside groups and agencies. These liaison efforts are carried out on a project specific bases. For example, the National Coal Assessment will require contact with many agencies including the Bureau of Mines, the Federal Energy Administration and the Environmental Protection Agency.

The Regional Energy Studies Program has also initiated the formation of a State Advisory Panel to help in making our work more applicable to state needs. This advisory panel consists of one member (appointed by the Governor) from each of the states in the region, has an advisory and review role in the program, and meets 2-3 times per year.

Informal-Cooperative

Members of the RESP act as a participant or in an advisory/review capacity in regional and research forums. For example, we review and comment on work done in regional forums such as the New England River Basins Commission RALI project, the New England Regional Commission and the Region I Federal Regional Commission Energy Resources Development Task Force. Conversely, many segments of the user community act in a review capacity for the RESP research products: for example, the Issue Paper prepared as part of the perspectives study on the Electric Sector benefited immeasurably from the review and comment by several electric utilities and power pool planning committees.

Symposia

Symposia have been found to be a very effective means of establishing communication with the user community. One such symposium was held at Brookhaven in March 1976 in connection with the Perspectives study: over a two day period, several formal presentations and panel discussions, as well as informal workshops, were held to discuss the findings of the study with over 150 attendees, drawn from state, regional and federal agencies, public interest groups, industry, the electric utilities, the press, legislative staffs, and others. Similar symposia are planned as part of the National Coal Utilization Assessment.

The experience gained through interaction with regional organizations, industry, state agencies, university groups, and federal/regional representatives provides a broad base from which to develop an understanding of regional energy policies. This experience and knowledge has been useful in coordinating existing RESP research with that of the other agencies in the region and designing an integrated and iterative energy program. For example, The Energy Research and Development Administration capitalized on this experience in preparing for its 1976 New England Regional Public Meeting, for which the RESP prepared a briefing book for ERDA personnel.

3.2 Institutional Analysis

As discussed in the introduction (and throughout this report) the diversity of factors required for developing energy policy and the distribution of affects which such policies engender often are not compatible with the levels of government which implement energy policies in the manner most suited to protect and benefit their resources, environment, economy, and citizenry. An unfortunate corrolary to such a system is that there exist few provisions for regional implementation or regulation at the optimal scale for improved consideration of the effects of many types of energy development.

There are regional forums and interstate compact commissions (for example, the New England Regional Commission, the Appalachian Regional Commission, the Delaware River Basin Commission, the Northeastern Legislative Conference) which have active energy programs transcending state borders. The powers of such agencies are essentially fiscal and/or advisory: where limited regulatory powers have been conferred they have also been weakened by the political realities of implementation, since the basis for participation by state governments and federal executive agencies is self-interest, a fertile bed for fragmentation when developing consensus policy. Regional organizations also suffer from the limited perspectives of participants; state governments are inherently oriented to short or mid-term problems; federal agencies are restricted to concerns which affect their jurisdiction or function; and private organizations or public groups, when represented, are restricted along functional lines or by lack of technical knowledge.

On the other hand, such drawbacks have not prevented regional organizations from gearing up to deal with energy problems. Their efforts over the past three years have included: aid--both technical and financial--in establishing state energy offices; the creation of regional and state energy information systems; development of energy/economic/environmental data bases; analysis of short and mid-term energy policies; coordination and financial aid for energy related programs (for example, railroad development and energy conservation); and providing technical information and analysis on the potential state and regional impacts of specific national programs (such as petroleum development on the Outer Continental Shelf.)

Research conducted for the Regional Energy Studies Program indicates that if existing (or potential) regional organizations are to treat the phenomenological aspects of energy development they must overcome their divisive problems. Recent initiatives by the Coalition of Northeastern Governors, including the possible creation of a Regional Development Corporation by interstate compact, suggest that regionalization of energy concerns is increasingly recognized by state governments.[2] Whether the recognition of similar concerns is capable of translation into effective coordinated regional development is unclear. However, the similarity of energy problems certainly provides improved impetus for regionalization; at least in the conduct of energy affairs.

Failure to develop regional mechanisms for energy policy implementation will place the burden for policy implementation and regulation on state legislatures and executive agencies. Princeton University, under the aegis of the Regional Energy Studies Program, has conducted research that suggests that state legislatures have been marginally effective in dealing with specific energy problems. By focusing on, and intercomparing, siting initiatives in the northeastern states, Princeton has effectively defined the factors involved in weakening legislative siting (as well as other energy policy) initiatives. These factors include the establishment of legislative priorities (in several states, notably New Jersey, financial problems captured the legislative agenda); state and national elections; lack of adequate information; jurisdicational disputes; and the crisis-response mode of public policy formulation.[3]

Other studies of regional interest carried out under the institutional framework of RESP include analyses of the legal and regulatory framework of artificial islands for offshore energy facilities[4] and a case study of nuclear power and its opponents.[5] This latter study is, perhaps, particularly interesting for the insight it provides on the incentives for citizen opposition to nuclear power, and the interaction of citizen groups in combating this form of electric production. While recognizing the potentially problematic application of such research (such a study could be used to subvert citizen group tactics or, alternatively, to shore up their weaknesses) it is felt that citizen groups are a viable conduit of public sentiment on energy policy issues, and as such should be recognized and weighed in the policy formulation and implementation process.

NOTES TO SECTION III

1. J. Brainard, J.S. Munson, P.F. Palmedo, "A Briefing on the Energy Situation in New England", BNL 21918, October, 1976.

2. "Recommendations of the Energy Policies Panel to the Coalition of Northeastern Governors", The Coalition of Northeastern Governors' Conference, Saratoga Conference, November 13, 14, 1976.

3. D. Morell and G. Singer, "State Legislatures and Energy Policy in the Northeast: Challenge and Conflict in the Legislative Arena," Draft Report, Princeton University, Oct. 1976.

4. D. Backstrom and M. Baram, "Artificial Islands for Cluster Siting of Offshore Energy Facilities: An Assessment of the Legal and Regulatory Framework", BNL 50566, June 1976.

5. L. Lewis and D. Morell, "Nuclear Power and Its Opponents: A New Jersey Case Study", Draft Report, Princeton University, Oct. 1976.

IV. REGIONAL DATA & MODELS

Central to the overall program is the assembly of an adequate information and data base, including background information on regional geography, population distribution, meteorology, industrialization; detailed information on all aspects of the energy system including fuels transport, conversion, transmission (of electricity) and end use in all residential, commercial, industrial and transportation sectors; pollutant emission characteristics for all elements in the system; environmental quality information; and economic data.

Whilst the collection and organization of such data in all of the above categories is continuing effort (aided in the past year by the acquisition of SYSTEM 2000, a sophisticated data base management system--see Section 4.1.5, below), the past year has seen special emphasis on air quality and air emissions data. This emphasis was mandated by the recognition that one of the key issues associated with the increased utilization of coal in the Northeast concerned air quality and related health impacts whose analysis necessarily required extensive quantitative information on emissions and air quality, and organized in such a way as to be efficiently accessible by the air quality models to be used in the forthcoming National Coal Utilization Assessment (See below, Sections 8.1 and 8.4). In the current Fiscal year, emphasis will shift from air to water, with the assembly of a similarly comprehensive data base on water quality and water emissions.

A second capability crucial to the objectives of the Regional Studies Program is the ability to study the interaction of the energy system with the regional economy. To this end we have initiated a program of energy/economic modelling that has as its ultimate objective the establishment of a linked ensemble of regional energy system, input-output, and econometric models. These can be coupled to their national couterparts already developed at the BNL National Center for the Analysis of Energy Systems. In the past year we have commenced work on a multi-regional linear programming model of the United States, an activity detailed in Section 4.2. Given the urgent economic problems of the Northeast, and the obvious links between energy policy and the ability to attain the economic revitalization of the region, the subsequent extension of the energy system model to a regional input-output formulation of the economy will receive high priority for the latter part of 1977 and FY 1978.

4.1 Data Assembly and Analysis (C.M. Benkowitz)

The acquisition and analysis of the data needed by the Regional Energy Studies Program (RESP) has continued during the program's second year. Particular attention has been focused on data that can be used to characterize air quality in the region and the impacts on health and the environment of alternative strategies for the use of coal.

Acquisition of air quality and emissions data was initiated by contacts with the principal repository of such data, the Environmental Protection Agency (EPA) through its National Aerometric Data Bank (NADB) for air quality data and National Emissions Data System (NEDS) for the emissions inventories. Initial sets of both types of data were obtained and analyzed to familiarize ourselves with quantity and quality of the data and to develop computer methodology to facilitate its storage and retrieval and manipulation. In order to expedite further acquisition of data from EPA, an interagency agreement between ERDA and EPA's National Computer Center at Research Triangle Park, N.C. is being completed.

Contacts were also initiated with selected state agencies in the northeastern U.S. to inquire about quality and availability of data. Several states responded with quality assessments and data sets that were either not yet available from EPA or were collected independently of those sets being submitted to EPA.

4.1.1 Air Quality Data

Air quality data currently at BNL includes:

a. NASN (National Aerometric Surveillance Network) observations for 1957--part of 1974 (not all years for all pollutants) for all of U.S.

b. NADB (National Aerometric Data Bank) observations for New York State and Connecticut for 1957--part of 1974 and for Delaware for 1959-1974.

c. New York City Department of Air Resources Network observations for SO_2 (/71-9/74), smoke-shade (11/68-8/74) and CO (1/69-9/74).

d. Boston data--data developed for Boston Transportation Control Plan. CO and ozone observations for 5 stations in the Boston area.

e. Computer readable directory of air quality monitoring sites.

f. New York State air monitoring network--total suspended particulates (TSP) data for January to August 1975; continuous air monitoring network--air quality and meteorological data for January to August 1975.

g. Precipitation chemistry data--NOAA/EPA network, 1972-1974.

h. SO_4 =, SO_2, TSP data prepared by Environmental Research & Technology, Inc. for the Electric Power Research Institute. The sulfate Regional Experiment planning study EPRI project #RP485 contains SO_4 =, SO_2, TSP, temperature, dewpoint, wind direction, wind speed, pressure, rain, weather and clouds for eight sulfate stations--midwest to Altantic states.

i. Air quality data collected by manual methods for 1970-1973 by CHAMP (Community Health Air Monitoring Program).

An initial investigation of the quality of the data in these data sets was undertaken. Discussions with personnel of various offices of the EPA have led to the following conclusions: Although in general the accuracy of data in the NADB is highly uncertain, there are sets of data contributed to NADB which are of known relatively high accuracy. Such sets are those from relatively recent established continuous air monitoring systems (CAMS). Stations in CAMS networks perform essentially completely automated analyses for an extensive set of pollutants with frequent periodic calibration checks. For some well established networks, such as that in the state of New York, the accuracy of the data for at least some of the pollutants can be stated. With this knowledge in mind, lists of CAMS stations for the states of New Jersey, New York, and Connecticut have been obtained, together with their SAROAD (Storage and Retrieval and Aerometric Data System) site code designations, so that data for the CAMS networks in these states may be readily retrieved from the NADB data for these states.

In general, for all NADB data, both from CAMS networks and from networks with manually operated stations, the individual agencies contributing air quality data must be contacted in order to determine what quality control measures were associated with data collection. Additional considerations underlying assessment of data quality include the fact that important problems associated with siting of sampling stations are not presently dealt with in federal standards. Guidelines for siting and for other quality control factors are only just becoming available. Interlaboratory comparisons of accepted analytical methods, conducted under nominally ideal conditions, show very large laboratory to laboratory variations in results of analyses of identical samples. The time scale for implementation of a good quality assurance program is about five years.

Prototype computerized data bases were established using a subset of the air quality data received. A brief study* of air quality data on SO_2, $SO_4^=$, and TSP was undertaken. The intent of the study was, first, to gain some experience in the examination and manipulation of such data, and, second, in so doing, to update the study by N. Frank[1] on trends in the distribution of SO_2, $SO_4^=$, and TSP in the northeastern U.S. and to analyze the data used in the updating study for seasonal differences in the manner used by Hitchcock.[2] The first goal was accomplished as was the second, but the results of the updating of the two earlier studies were inconclusive because of limited data.

NASN data for the years 1964-1972 were used. Data were analyzed for all stations in the northeastern states (Connecticut, Delaware, Illinois, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, Virginia and West Virginia), for which there were data for seven or more out of the nine years. Only eleven such stations were found. Ten of these were in cities.

For each pollutant at each station the following statistics were first calculated: yearly geometric mean, quarterly geometric mean, difference between summer and winter means. Then, in the evaluation of trends with time at each station, we calculated the arithmetic averages

*Study was conducted in cooperation with Dr. F.B. Hill of the Molecular Sciences Division.

of the annual geometric means and the Kendall correlation coefficient[3] for the geometric means. The Kendall correlation coefficient varies between -1 and +1, a negative coefficient indicating a decrease in geometric mean with time, and a positive coefficient, an increase with time. The probability of no correlation was also calculated. In the evaluation of summer-winter differences, the arithmetic average of the yearly differences was calculated, and a one-tailed Student t-test was carried out to determine whether a postive difference (summer mean greater than winter mean) was significant[4].

The results are summarized in Tables 1 and 2.

As seen in Table 1, ten of the eleven stations showed a statistically significant downward trend in TSP, nine for SO_2, and two showed a negative trend for $SO_4^=$. No significant upward trends were found.

The summer-winter difference study (Table 2) was undertaken with the biogenic sulfur problem in mind. This study was inconclusive because of the station locations.

The acquisition of air quality data, the development of second generation prototype data bases and the interactions between such data bases and modeling programs are currently proceeding. An extension of the $SO_2/SO_4^=$/TSP study, as well as other analysis activities, will also be undertaken.

4.1.2 Emissions Inventory Data

Emissions inventory data currently at BNL includes:

a. Point sources--NEDS non-confidential point source data for all the U.S.

b. Area sources--NEDS area source data for all the U.S.

c. New York City Department of Air Resources--point and area source inventory for New York City.

d. New York State Department of Environmental Conservation--point source inventory for N.Y. State. Partial area source inventory not on computer compatible form.

TABLE 1

TRENDS IN ANNUAL GEOMETRIC MEANS OF POLLUTANT CONCENTRATIONS, 1964-1972

STATION	SO_2		$SO_4^=$		TSP	
	Kendall Coefficient	Probability of No Correlation	Kendall Coefficient	Probability of No Correlation	Kendall Coefficient	Probability of No Correlation
Hartford, Conn.	-0.611	.63%	0.056	45.97%	-0.667	0.29%
New Haven, Conn.	-0.429	5.32%	0.214	27.42%	-0.500	2.23%
Baltimore, Md.	-0.556	1.24%	-0.278	12.98%	-0.778	0.04%
Newark, N.J.	-0.944	<0.01%	-0.722	0.12%	-0.722	0.12%
New York, N.Y.	-0.667	0.29%	-0.571	1.56%	-0.786	0.09%
Cleveland, Ohio*	-0.611	0.63%	0.222	23.84%	0	54.03%
Dayton, Ohio	-0.071	35.98%	0.357	13.75%	-0.643	0.71%
Youngstown, Ohio	-0.667	0.29%	0.222	23.84%	-0.611	0.63%
Pittsburgh, Pa.	-0.778	0.04%	0.429	8.94%	-0.389	5.97%
Providence, R.I.	-0.428	5.43%	-0.333	9.01%	-0.722	0.12%
Charleston, W.V.	-0.111	30.61%	-0.167	23.84%	-0.389	5.97%

*Suburban

TABLE 2

AVERAGE POLLUTANT CONCENTRATION SUMMER-WINTER DIFFERENCES 1964-1972

STATION	SO_2		$SO_4^=$		TSP	
	Arithmetic Mean	Probability	Arithmetic Mean	Probability	Arithmetic Mean	Probability
Hartford, Conn.	-52.30	0.14%	-4.39	1.05%	-23.92	0.78%
New Haven, Conn.	-52.45	0.09%	-9.06	0.05%	-36.60	0.08%
Baltimore, Md.	-81.82	0.52%	0.095	47.66%	-13.18	20.70%
Newark, N.J.	-91.88	0.45%	-2.05	13.72%	-3.11	33.62%
New York, N.Y.	-218.53	0.05%	-7.25	8.36%	-38.57	8.50%
Cleveland, Ohio	-35.79	1.30%	1.48	9.10%	4.39	32.66%
Dayton, Ohio	-8.54	3.25%	3.27	1.24%	10.60	6.84%
Youngstown, Ohio	-41.84	0.04%	3.19	2.04%	6.98	22.95%
Pittsburgh, Pa.	-21.51	1.50%	5.60	0.26%	-0.86	46.78%
Providence, R.I.	-105.57	0.42%	-4.02	0.60%	-23.03	0.59%
Charleston, W.V.	-3.46	10.55%	8.58	2.41%	-4.70	40.91%

e. Rhode Island Dept. of Health--area source inventory in gridded form not directly computer compatible.

f. ERT prepared for EPRI--gridded emissions inventory for northeastern U.S.

Point Sources: Inquiries have been made to a number of states and to various offices of the EPA concerning the compilation, completeness, and accuracy of the NEDS data, with the following results. Emissions data for point sources include information on source location, stack parameters, plant rating, fuel data, etc., as well as data on emission rates of the primary criteria pollutants--particulates, sulfur dioxide, nitrogen oxides, hydrocarbons, and carbon monoxide. While emission rates may be determined by any of several methods, involving stack tests, material balances, or the use of emission factors, the emission factor method is most often used. When the inventory for a state is said to be good, what is usually meant is that it is relatively complete. No assessment of accuracy was available.

A computer program has been written to run edit and validation checks on NEDS format point source emission data and to obtain statistics on methods of emission rate determination. The principal error discovered to date is incorrect location coordinates, that is, coordinates are either missing or not even within the bounds of the state. The principal method of emission rate estimation is that using emission factors though others are used often enough so that they cannot be ignored.

NEDS point source inventory data for the northeastern U.S. as well as the point source inventories obtained from New York State and New York City agencies were loaded into prototype computerized data bases for analysis. The following are some of the results to date:

1. Slightly over 10% of the point sources listed in the data obtained from NEDS had incorrect or missing location parameters. With the help of available maps most of these errors were manually corrected.

2. The data obtained from NEDS listed 295 plants and 891 points for the State of New York. The data obtained from New York State

listed 5588 plants and 23601 point sources for the State of New York. Both data sets use NEDS developed identification codes.

3. The data obtained from New York State listed only 8 plants and 28 points for New York City. The data obtained from New York City listed 176 plants and 268 points for the city.

4. The data obtained from New York City included point sources located outside of the New York City area but within Air Quality Control Region #43. A follow-up telephone call to the appropriate city agency revealed that non-N.Y. City data was taken from a NEDS inventory for 1969. Therefore, only the data for New York City proper was considered from this subset. A cross reference table between the identification codes used by NEDS and the identification codes used by New York City was compiled. Similarities and differences in equivalent data from the two sources were annotated.

5. Reports were generated from the computerized portions of the NEDS data to allow an initial comparison with the data supplied by the Federal Power Commission reports. Results were tabulated via worksheets and are to be analyzed. Preliminary scanning shows that in a majority of cases the data does not compare well.

Based on the experience gained in the above described study computerized data bases for emissions inventories are being redesigned. A comprehensive emissions inventory for the Northeast will be used as a prototype to attempt to develop a methodology for pulling together data from different sources to compile a best estimate inventory. Results will be extended to other areas of the country.

Area Sources: Emissions data for area sources have been received from EPA/NEDS and several state agencies, not all of which are in computer compatible form. Preliminary analysis has concentrated on the NEDS data set since this set is the most comprehensive and is in computer compatible form.

A computer program was written to do an overall scan of the NEDS area inventories. No data was found for four states: Connecticut, New York, Rhode Island and Texas. Data for West Virginia for NO_x, HC and CO was also missing. Data for the other states is on a county basis. Dates of inventories ranged from 1970 to 1973, the majority being 1972.

Studies of gridding and geocoding procedures for area sources have been started. Interfacing of area source inventory information with atmospheric and economic models is also in progress. Compilation of data from different sources and its incorporation into computerized data base(s) with easy user interface will follow shortly.

The acquisition of both point and area source emissions data is continuing with emphasis being placed on building as complete an inventory as possible. User interface via computerized data bases will be implemented. Quality analysis studies will be continued and/or expanded as manpower commitments permit.

4.1.3 Demographic Data

Demographic data currently at BNL includes:

a. County based population tape-population count, by states and counties, broken down by age and sex for years 1950, 1960, and 1970.
b. U.S. Census--County and City Data Book, 1972.
c. Adjusted 1970 County population by single years of age, by race and by sex.
d. OBER's Projections Series E--all six tables.

Demographic data is currently being developed as input to the population projection project. County based information from (a.) and (c.) above was aggregated as needed and along with the OBER's population projections, is being used by a projection model. A prototype computerized data base has been built using the SMSA Table information from the City and County Data Book. Geocoding methods used in conjunction with demographic data are being studied and their correspondence with codes used by EPA with the NADB and NEDS data is being developed. Computerized mapping capabilities are also being developed.

4.1.4 Inter Laboratory Coordination

At the start of RESP representatives of the various laboratories involved in the program recognized the need for a more uniform framework for data exchange. In order to avoid duplication of effort and encourage cooperation, initial inter-laboratory meetings were held in which existing system capabilities were reviewed, bilateral data exchanges were initiated and the need of a more formalized method of exchange was recognized.

Although hampered by lack of funding, a working committee, formally known as the Inter Laboratory Working Group for Data Exchange (IWGDE), brought together members from all seven ERDA National Laboratories and has succeeded in establishing a forum for interlaboratory cooperation. Among the IWGDE's accomplishments for FY 76 are the development of a standard for a computer compatible medium for data exchange and the initial implementation of this standard by cooperative effort between some of its member laboratories. A bilateral effort by BNL and Los Alamos Scientific Laboratory (LASL) is currently developing this implementation at both installations simultaneously. Multipath data exchanges were also nurtured and carried to fruition under the IWGDE umbrella. Further details are to be found in the IWGDE annual Report.[5]

At the request of ERDA a special interest working group of the IWGDE was formed to study problems associated with the use of different geo-coding systems. This working group has met several times, has developed a "strawman" set of proposals and has conducted some small studies on the use of specific geocoded based systems. Details of its activities is also contained in the IWGDE Report.[6]

The programmatic context of the IWGDE work extends beyond RESP to all of the Division of Biomedical and Environmental Research assessment activities. It is in this framework, and with the hope of direct funding from ERDA, that the IWGDE will continue its work. Completion of the development and implementation of the exchange standard and further work in areas such as geocoding, graphics, etc., are important topics to be addressed by this committee.

4.1.5 Data Base Management

A careful evaluation was conducted of BNL's data needs on one hand and its computerized data handling capabilities on the other hand. It became clear that the central computing facility, designed primarily for high speed computation, was not well equipped to handle the data needs of RESP. An assessment of software packages available was conducted and SYSTEM 2000, a data base management system marketed by MRI Systems Corp., Austin, Texas, was installed for a trial period at BNL's central facility. On completion of the trial period, SYSTEM 2000 was accepted and is now operational at BNL.

Experience with the capabilities and use of SYSTEM 2000 were gained by building and exercising prototype data bases as described in the Data Collection and Analysis section of this report. SYSTEM 2000 will form the core of the data handling facilities being developed for the use of RESP data.

4.2 Regionalization of the Brookhaven National Energy System Optimization Model (R. Goettle)

4.2.1 Introduction

As research, development, and demonstration programs focus on the national implications of specific technologies, it is clear that regional evaluations must be performed regarding the potential implementation requirements and induced effects associated with actual penetration. Regional variations in climatic conditions, environmental issues and possible policy responses, the access to various fuel forms, and the prevailing price and pattern of energy consumption obviously affect the course of such implementations. Further influences on appropriate selective choices derive from the distributional considerations of present and future energy forms. Thus, regional transportation options and their related costs are important components of the decision calculus. To address adequately the regional economic, energetic, and environmental implications of national energy policies and programs and to assist regional authorities in their own policy formulation requires the development of an integrated national/regional analytical structure and capability.

A multi-regional linear programming energy model of the United States is currently being developed at the National Center for Analysis of Energy Systems, Brookhaven National Laboratory. This activity is part of the continuing Energy Systems Studies[7] and Regional Energy Studies Programs. As planned, the single-period model optimally allocates regionally produced energy resources and products and selects the optimal regional mix of energy supply, conversion, and demand technologies to meet projected regional energy demands (according to a selected optimization criterion). Regions (defined to be the nine Census regions of the U.S.) are linked by both imports and exports of natural resources and converted fuels or products, including electricity. Resources are characterized by region specific supply functions, and regional energy demands are specified in terms of functional end-uses (e.g. space heat, air conditioning, process heat, and motive power).

Potential objective functions for the model include:

1. Annual average system cost, including amortized capital, fuel, and operating cost (end-use device costs may also be incorporated);
2. Annual marginal system cost; (this is based on the implementation of upward sloping resource supply curves and the distinction between existing and new conversion capacity.)
3. Capital requirements;
4. Resource use;
5. Petroleum imports or total petroleum consumption;
6. Environmental effects (e.g. the joint consumption of non-energy commodities or the joint production of specific emissions or a linear combination therof).

For a given national specification, sensitivity analyses of the assumptive demand, supply, cost, efficiency, and environmental structures can be conducted. Such analyses provide information regarding the response of the national/regional optimal allocation and technology mix to changes in the model's exogenous parameters under a single decision criterion. Alternatively, multi-objective analyses can be performed utilizing all or some of the aforementioned objective functions[8]. Here, the purpose is to establish trade-off loci for the variety of considerations which enter policy assessments and comparisons. The flexibility afforded by the formulation of the multi-regional model permits the construction of a geographic hierarchy of multi-objective studies; such analyses can be performed in a national objective vs. national objective, national objective vs. regional objective, and regional objective vs. regional objective framework.

These suggested analyses, utilizing an integrated multi-regional energy model, provide useful information in support of the judgmental evaluation and assessment activities that necessarily address the more unquantifiable issues.

4.2.2 Model Structure

The multi-regional model represents an extension of BESOM[9] and the Reference Energy System (RES)[10] developed at Brookhaven National Laboratory. As in these models, the basic structural philosophy is to trace all of the possible paths through which a Btu as an energy source can find its way to an energy demand. For example, a Btu of a specific type of coal that moves to a coal gasification plant and through a pipeline is eventually used to satisfy a residential demand for space heat. The intermediate energy form (IEF), in this case coal (then gas), is defined as the Btu's of energy input to the demand -- coal gasification plant (then gas to the burner). Each IEF has associated with it a demand efficiency and a supply efficiency. The demand efficiency is the energy loss as the IEF is converted into an energy product (e.g. space heat). The supply efficiency is the energy loss either from the point of extraction to the IEF in the case of a natural resource or associated with the conversion of one IEF to another IEF. In addition to these features, the multi-regional model incorporates an expanded set of IEF's (e.g. the oil IEF is decomposed into gasoline, jet fuel, mid-distillate fuels, residual oil, and an "other" category). Also, specific model transportation efficiencies are included for all delivery points on a particular path (e.g. coal by unit train and/or slurry pipeline to a coal steam electric plant).

In this section, a brief description and elaboration of the model's structure is presented.

1. Regional Resource Extraction Activities

Resources (coal - by type, oil - by type, natural gas, U_3O_8, and certain of the renewable resources) are characterized by step function approximations to upward sloping supply curves. Thus, additional indigenous extraction of a resource beyond the limit allowable on any supply curve segment is only available at a higher cost. Total resource extraction by resource type is the sum of the production levels across all segments of the supply curve.

2. Intraregional Primary Resource Movements

Extracted resources are postulated to move intraregionally by various modes to resource pools where they are either utilized as technology inputs or exported to other regions, including abroad. Thus, total available production (from 1) equals total intraregional shipments by all modes.

3. Regional Resource Pool Balances

Resources may be either natural (extracted), synthetic (created from other resources), or imported from like pools in other regions. A region's pooled availability of a particular resource equals the combined amounts from these three sources (if applicable) less any modal transportation losses associated with their delivery to the pool. Conversely, outflows from the pool either move to other regions or become inputs to facilities located within the region. For each resource pool in a region, inflows must equal outflows.

4. Regional Conversion Activities

Product IEF's are produced through the appropriate technological conversion of input IEF's (e.g. in a region crude oil of type m processed by a refinery of type n yields a product slate of gasoline, jet fuel, mid-distillate fuels, residual oil, and miscellaneous petroleum products).

5. Regional Product Pool Balances

Inflows to regional product pools originate from either indigenous production (1 or 4 above) or interregional trade (imports from other regions net of any transportation losses). Product IEF's may be exported to other regions and, depending on the product, used to satisfy end-use demands (e.g. processed gas to space heat), used as an input to other processes (e.g. residual oil to oil steam electric plants), or added to regional resource pools (e.g. coal syngas additions to a regional gas pool). For each product pool in a region, inflows must equal outflows. It should be noted that for some IEF's (e.g. coal, processed gas) the resource and product pools are one and the same.

6. Regional End-Use Demands

Product IEF's are postulated to move intraregionally by various modes from product pools to users where they are consumed by various end-use devices (e.g. residential space heat burners, industrial boilers, automobiles). Product IEF's to meet demands are modified by both the demand efficiency of the end-use device and the transportation efficiency associated with delivering products from their pools to their point of consumption.

Note: Transportation losses are only assigned to non-synthetic primary resources moving to regional resource pools, product IEF's moving to regional product pools from other regions, and product IEF's going to final demands. Resource pools, product pools (to the extent they are different) and conversion activities are postulated to exist at the same spatial point.

7. The Electric Sector

The formulation of this sector is intended to account for both the exogenous seasonal (winter, summer, spring) and daily (day, night) characteristics of electricity demand in the region and the endogenous demands for which the "regional utility" can exercise both temporal and quantitative choice (e.g. fuel cells, pumped storage, electrolytic hydrogen). As with other product IEF's, the structure of this sector explicitly permits the interregional transmission of electricity.

8. Additional Constraints

In addition to the supply curve limitations on resource extraction, the pool balances, and the required satisfaction of end-use demands, other limitations enter the formulation to complete the model's structure. These include:

a. Capacity constraints on various conversion activities or technologies;
b. The distinction between existing and new capital stock;

c. The non-substitutable use of certain product IEF's for certain end-use demands;

d. Export/import limitations;

e. Modal transportation/transmission capacities;

f. The environmental effects associated with the aforementioned activities.

4.2.3 A Diagrammatic Exposition of the Multi-Regional Model

The basic structure of the multi-regional model is represented in a set of flow diagrams which characterize the energy system for a respresentative region, denoted I, IEF flows, denoted J, are indicative of the trade potentials which exist between region I and the other regions in the model (including a foreign sector). Table 3 displays a dictionary of the nodal codes employed throughout the subsequent figures. Figures 3 and 4 depict the fuel cycles for the various resources (coal, oil, methane, renewable, and nuclear) contained in the system. Figure 5 illustrates the structure of the electrical sector in region I. Finally, in Figure 6 regional IEF flows to functional end-use demands are shown.

4.2.4 Model Development and Status

The above version of the multi-regional is to evolve through several stages of development. Such a strategy expedites the generation of our regional analytic capabilities and minimizes the data and formulation requirements at each stage. The initial stage, completed at the time of this writing, involved the use of BNL's static national model, BESOM. The BESOM 1985 cost and constraint structure was replicated and made region specific for the nine census regions of the United States. Regional resource supplies, conversion capacities, and energy demand data for the year 1972 were input to the demonstration model.[5] Regions were linked through the creation of national resource pools for an aggregate coal type, a crude equivalent petroleum resource, and natural gas. For a given resource, regions with excess supply could and had incentives to export

TABLE 3

Dictionary of Nodal Codes for Multi-Regional Energy Model

CHARACTER CODE	DESCRIPTION
AIR	Air Transportation Demand
ARC	Total Air Conditioning Demand
ARH	Air Conditioning from Heat Pump
AUT	Total Automobile Demand
BAE	Base Load Electric
CCC	Coal Steam Electric Combined Cycle
CLQ	Coal Liquefaction
CNT	Central Station Electric
C_m_	Crude Oil of Type m
CSE	Coal Steam Electric
DIE	Distributed Electricity
DST	Distillates Available
ELY	Electrolysis
FBO	LMFBR
FUS	Fusion
GAS	Processed Gas Available
GEO	Geothermal
GFC	Gas Fuel Cells
GSE	Gas Steam Electric
GSL	Gasoline Available
HFC	Hydrogen Fuel Cells
HTO	HTGR
HYD	Hydrogen (both from coal & electrolysis)
H2O	Hydroelectric
H_n_	Refinery of Type n
INE	Intermediate Load Electric
IOR	Iron Ore Reduction
ISU	In-situ Shale Oil Extraction
JET	Jet Fuel Avaialble
LBG	Low BTU Gas
LWO	LWR
MFC	Methanol Fuel Cells
MOL	Methanol Available
OCC	Oil Fired Combined Cycle
OFC	Oil Fuel Cells
OGT	Oil Fired Gas Turbine
OSE	Oil Steam Electric
OTH	Other Petroleum Products Available
PCH	Petrochemicals Demand
PNP	Plutonium National Pool
PPS	Pumped Storage
PRH	Total Process Heat Demand
PVT	Solar Photovoltaic
RAL	Total Railroad Demand
RET	Shale Oil from Retorting
RSD	Residual Available
S_k_	Stripmined Coal of Type k
SCC	Synthetic Crude from Coal
SDS	Solar Direct Storage
SEA	Ocean Thermal
SES	Solar Electric Storage
SFD	Spring-Fall Days
SFN	Spring-Fall Nights
SGC	Synthetic Gas from Coal
SGO	SNG from Oil Plant
SMD	Summer Days
SMN	Summer Nights
SPH	Total Space Heat Demand
SPP	Space Heat from Heat Pump
SUN	Solar Direct
TBS	Truck, Bus and Ship Total Demand
TES	Total Energy Systems
THM	Solar Thermal
TNP	Thorium National Pool
TOE	Transmitted Electricity
U_ℓ_	Underground Coal of Type ℓ
UWS	Urban Waste
UOR	Enriched Uranium Available
WID	Winter Days
WIN	Winter Nights
WML	Windmills
WTH	Total Water Heat Demand
I	Region Depicted on Diagrams
J	Other Regions (Excluding I)

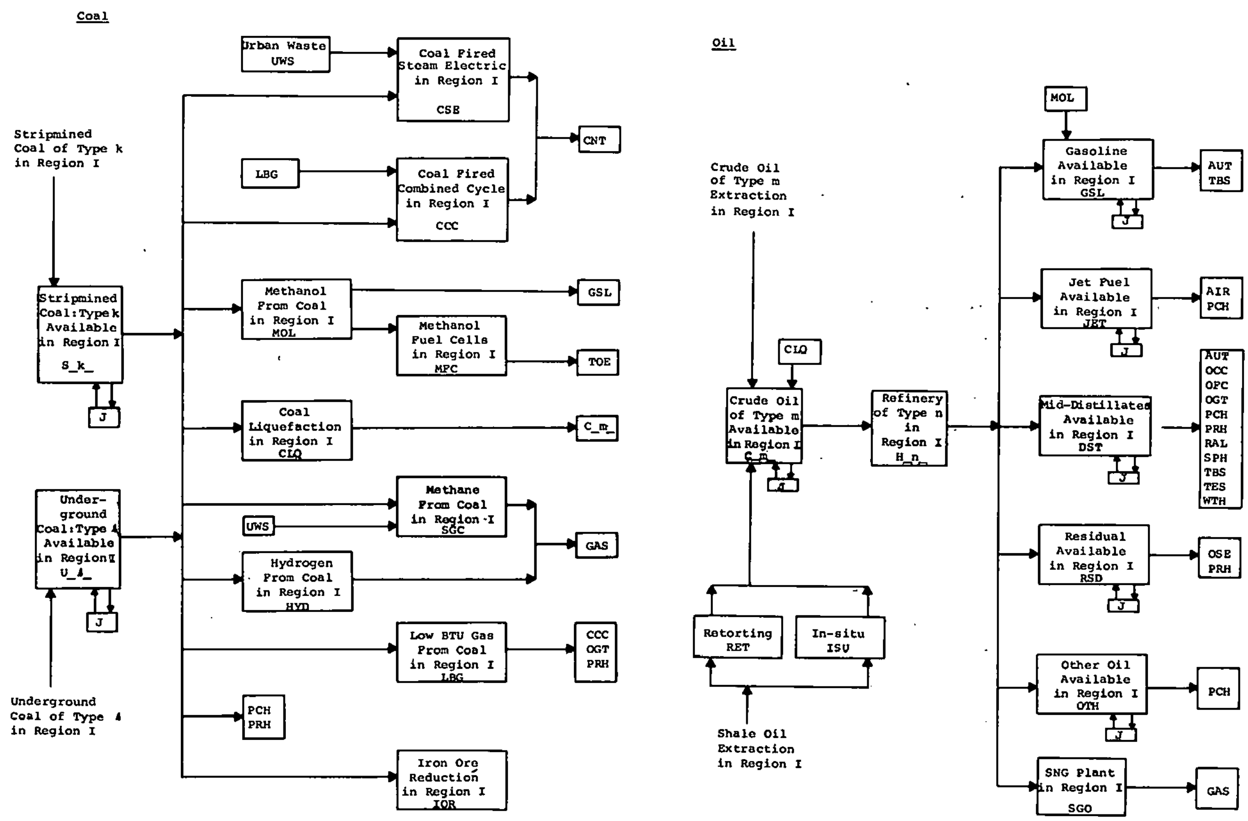

Figure 3. Coal and oil fuel cycles for multi-regional model.

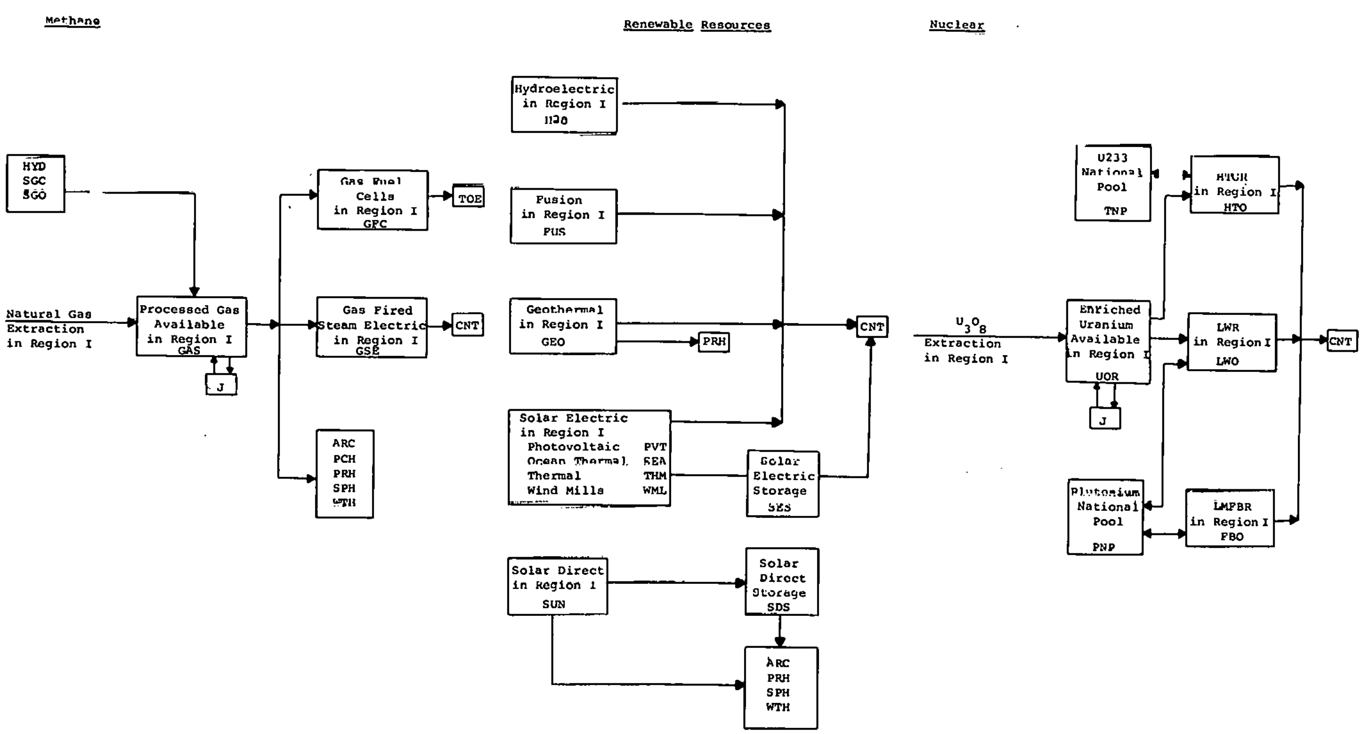

Figure 4. Methane, renewable resource, and nuclear fuel cycles for multi-regional model.

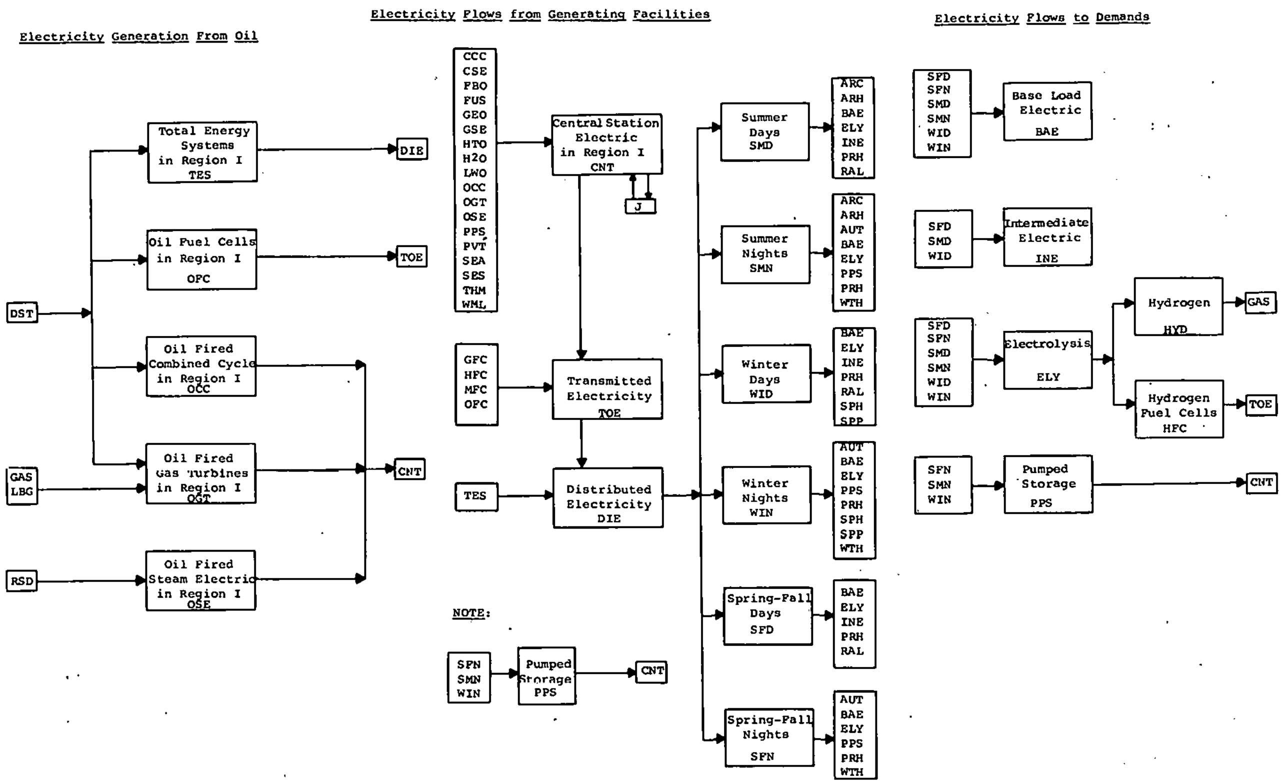

Figure 5. Electric sector representation in multi-regional model.

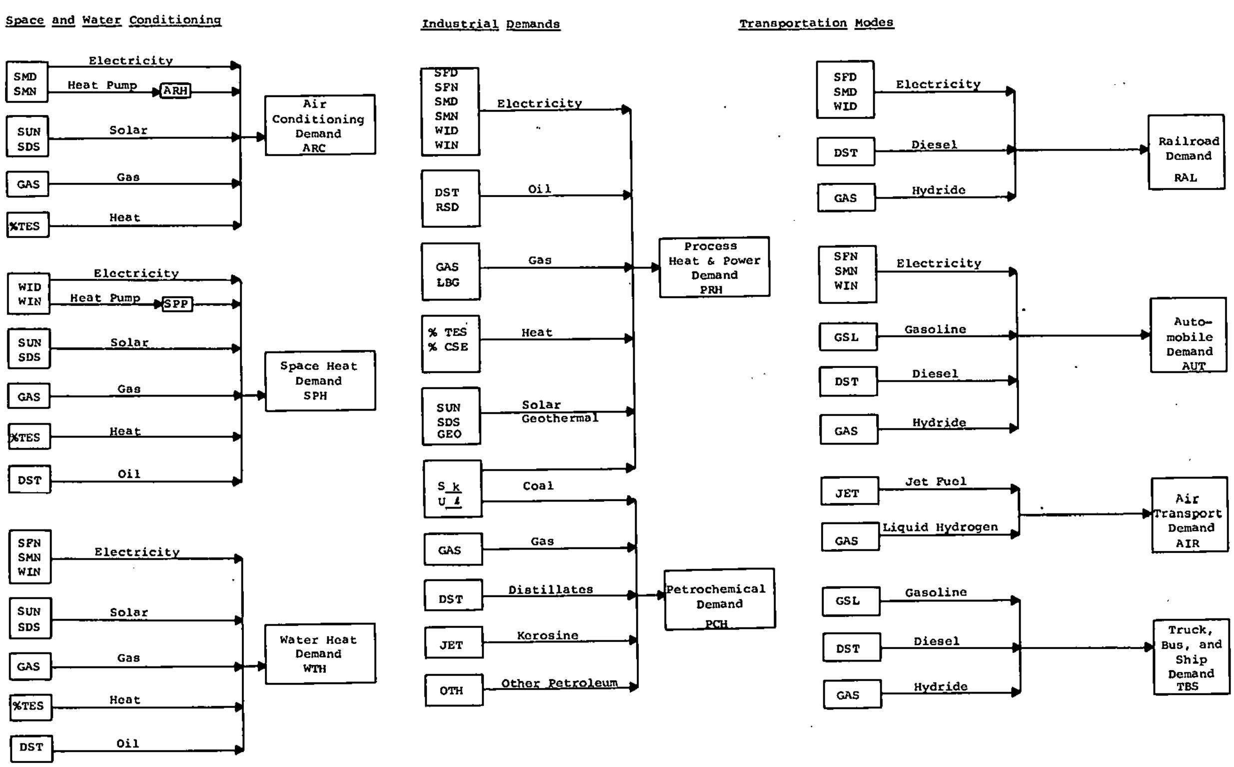

Figure 6. Energy demand structure for multi-regional model.

to the national pool whereas regions with excess demand were forced to import from this pool at the national cost. Balance equations for the national pool were created and these included the potential for foreign resource transfers. The complete model was tightly constrained so as to reporduce the 1972 regional technology mix of energy supply, conversion, and demand described in Hermelee.[11]

The next phase of model development, representing work-in-progress, involves several modifications to the above 1972 validation run. First, the 1985 national energy system cost structure will be altered in accordance with the 1972 relative costs. Further, with the national pool formulation still in place, the regional transaction prices to or from the national pool will be changed to reflect more realistic marginal gains or losses derived from regional export or import activity. This version of the model is to be implemented and sensitivity analyses performed with varying potentials for interfuel substitution. Such analyses, while not addressing the important issues of optimal interregional energy flows, would nevertheless provide useful information on the cost implications of satisfying regional energy demands with regionally extracted and converted resources and/or imports.

Subsequently, the national pool concept will be eliminated in favor of regional pools with explicit region to region trade flows and costs. The model will be fitted with upward sloping supply curves for an aggregate coal and domestic crude type, and natural gas. Additional resource pools and trade flow options will be opened for nuclear fuels and electricity. Also the environmental equations, incorporating both intra and interregional coefficients, would be made operational. As this version is truly multi-regional in scope, regional variations in all costs and conversion or transmission efficiencies would, to the extent possible, be explicitly considered. The successful completion of this final task would provide a necessary linkage between our national energy-economic models and energy-economic-environmental analytic capabilities at the subregional level.

Parallel to these latter activities and drawing support from them will be the formulation of the multi-regional model of previous sections.

This would include, but would not be limited to, more detail in the nuclear sector, more varieties of coal and crude oil, the addition of alternative refinery types and product (IEF) yields, additional transportation options, and the incorporation of capital cost-capacity scaling factors for new facilities.

NOTES TO SECTION IV

1. N.H. Frank,"Temporal and Spatial Relationships of Sulfates, Total Suspended Particulates and Sulfur Dioxide,"Air Pollution Control Association Annual Meeting, Denver, Colo., June 1974.

2. D.R. Hitchcock,"Atmospheric Sulfates from Biological Sources,"Air Pollution Control Association Annual Meeting, Boston, Mass., June 1975.

3. M.G. Kendall,"Rank Correlation Methods,"Charles Griffen and Co., Ltd., London (1962).

4. B. Ostle,"Statistics in Research,"Iowa State College Press (1954).

5. ERDA Interlaboratory Working Group for Data Exchange (IWGDE)--Annual Report for Fiscal Year 1976. LBL-5329.

6. Ibid.

7. Supported by the Assistant Administrator for Planning, Analysis, and Evaluation, U.S. ERDA.

8. K.C. Hoffman, et al., "Multi-Objective Analysis of ERDA Combined Technology Scenarios," BNL 21091 (Jan. 1976).

9. E.A. Cherniavsky, "Brookhaven Energy System Optimization Model," BNL 19569 (Dec. 1974).

10. M. Beller, ed., "Sourcebook for Energy Assessment" BNL 50483 (Dec. 1975).

11. Alan L. Hermelee, "Regional Reference Energy Systems," A draft topical report prepared by BNL for the Electric Power Research Institute (Oct. 1976).

V. CONSERVATION ANALYSIS

The critical importance of energy conservation and increased energy efficiency in dealing with national energy problems is widely recognized. Although considerable analysis has been carried out of the feasibility of certain conservation measures at the national scale, insufficient attention has been paid to conservation analysis at the state and regional scale. The problems and issues that are important at the state level are different than those at the national level; a given states' conservation of fuel oil during one period for example, may not guarantee that state increased supplies at a later time. Similarly, a tax to reduce industrial energy consumption in one state may induce industries to site in other states. Thus, there are benefits both to the states and to the country as a whole to take a regional view of energy conservation and, if possible, rationalize state energy conservation legislation on a regional basis.

5.1 Conservation Studies in Specific Demand Sectors

Analysis of conservation strategies and policy played a central role in the Perspectives study, and was incorporated as a component of both residential and commercial energy demand analysis (BNL 50552) and the Transportation Sector analysis (BNL 50554). In order to keep conservation options as art of the scenario analysis to tractable limits, the myriad conservation options were grouped into "packages", identified as "moderate conservation" and "strong conservation", the specific assumptions as shown on Tables 4, 5 and 6. These conservation cases were then integrated into the scenario analysis as discussed in Section II.

The various scenarios for the future evolution of the energy system of the Northeast invoked a wide variety of possible policy and technological developments. It is convenient to distinquish two categories of such developments: those oriented toward increased supplies, such as coal gasification and OCS resource development and those oriented toward improving the efficiency of energy utilization, such as increased appliance efficiencies and better insulation practices. A recent BNL study indicates that there

TABLE 4

ESTIMATED ANNUAL ENERGY SAVINGS BY FUEL TYPE/1985-2000
(In Btus x 10^{12})

Action	1985 Gasoline	1985 Diesel	1985 Total BTUs	2000 Gasoline	2000 Diesel	2000 Total BTUs
SPEED REDUCTION:						
-Enforce 55 MPH Limit for Autos	73.1	-	73.1	96.4	-	96.4
-Enforce 55 MPH Limit for Trucks	.9	14.9	15.8	1.4	21.1	22.5
-Optimum Cruising Speed for Airlines	-	19.1	19.1	-	54.0	54.0
-Reduce Speed of Maritime Vessels	-	128.0	128.0	-	3.4	3.4
MODIFY REGULATIONS:						
-Increase Airline Load Factors	-	114.1	114.1	-	305.3	305.3
-Relax Truck Weight/ Length Limits	-	23.0	23.0	-	67.0	67.0
COMMUTER CAR-POOLING						
-Achieve 50% Participation	130.0	-	130.0	160.0	-	160.0
PROMOTE PIGGYBACKING:						
-Economic Incentives for TOFC	3.0	23.1	26.1	3.6	45.5	49.1
PROMOTE PUBLIC TRANSIT:*						
-No Fare or Reduced Fare Transit	44.3	-	44.3	59.5	-	59.5
-Double Transit Fleet VMT	19.1	-	19.1	24.3	-	24.3
-Commuter Parking Tax	46.7	-	46.7	62.3	-	62.3
FUEL TAXES:						
-50% Increase in Price of Gasoline	300.0	-	300.0	390.0	-	390.0
NEW TECHNOLOGY:						
-High Speed Surface Transportation (TACV)	-	-	-	-	170.0	170.0
-Maximum Refinement of ICE	-	-	-	1,214.0	-	1,214.0
-Railroad Electrification	-	-	-	-	30.0	30.0
-Electric Cars	-	-	-	400.0	-	400.0
LAND USE:*						
-Energy Efficient Patterns for New Development	-	-	-	193.0	-	193.0
-Transit to Industrial/ Commercial Concentrations	-	-	-	90.0	-	90.0

*Estimated savings do not reflect increases in transit energy consumption

Source: Brainard et al, BNL 50550, p. 50.

TABLE 5

CONSERVATION CASES - TRANSPORTATION

Moderate Conservation Action	Potential Savings 1985	Potential Savings 2000	Savings in Projections (10^{15} Btu) 1985	Savings in Projections (10^{15} Btu) 2000
1. Reduce Speeds 2. Modify Regulations 3. Promote Piggybacking 4. Promote Car Pooling 5. Promote Public Transit 6. Tax Fuels	9-13%	12-20%	12%	12%
Strong Conservation				
1. All actions listed for Moderate Conservation 2. Refinement of ICE 3. Alteration of land use Patterns	17-20%	30%+	18%	34%

Source: Brainard et al, BNL 50550, p. 51.

may be substantial differences between these two categories of programs in terms of national benefits measured by the reduction in consumer expenditures for energy. The programs with the largest benefits (discounted to the present over a projected implementation schedule) are those aimed at the improvement of residential, commercial, and industrial end-use efficiencies, the delivery of total energy systems to the residential and commercial sectors, and improved auto propulsion systems - the "conservation," or end-use technologies and policies.

The advantage of end use technologies is even more pointed in the Northeast where regional employment considerations must be added to the criteria of choice. Conservation or demand oriented strategies are among the most employment intensive energy alternatives and, more importantly, can be used to directly eliminate regional structural unemployment. It is far easier to train and retrain unemployed residents for the purpose of engaging in traditional production activities than it is to provide

TABLE 6

SUMMARY OF CONSERVATION SCENARIOS: RESIDENTIAL AND COMMERCIAL

CONSERVATION MEASURES	LEVEL OF IMPLEMENTATION: BASE	MODERATE	STRONG
RESIDENTIAL - Space Heating			
1. Improved insulation in existing homes - retrofits of insulation, storm windows, storm doors, etc. in existing single-family homes.	12% to 15% savings per unit (depending on housing type) implemented at 1% of housing stock per year to 1985.	Same as base case but implemented at 2% per year to 1985.	Same as base case except implemented at 5% per per year to 1985.
2. Improved insulation in new homes - adoption of energy conservation building codes.	ASHRAE 90-standards on 10% of fossil fuel heated homes beginning in 1977. All electric homes built to standards that result in 40% savings over existing units.	ASHRAE 90-standards on 50% of fossil fuel homes beginning in 1977. Electric homes same as base case.	ASHRAE 90-standards on 100% of fossil fuel homes beginning in 1977. Electric homes same as base case.
3. Improved maintenance of existing oil and gas furnaces.	Average efficiency up 5% implemented at 1% of housing stock per year to 1985.	Average efficiency up 5% implemented at 2% per year to 1985.	Average efficiency up 5% implemented at 5% per year to 1985.
4. Improved design of new gas and oil heating systems.	New unit efficiencies up 10% over existing 1972 units.	Same as base case.	Same as base case.
5. Use of electric heat pumps instead of resistance heating.	50% of electric homes built between 1985 and 2000 heated by heat pumps.	20% of electric homes built between 1972 and 1985 heated by heat pumps and 70% of new electric homes from 1985 to 2000.	40% of electric homes built between 1972 and 1985 heated by heat pumps and 100% from 1985 to 2000.
6. Solar space heating in new homes	NONE	25% of homes built between 1985 and 2000 receive 50% of space heat demand from solar devices.	Percentage of homes increased over moderate case to 50%.
7. Lowered thermostats	70°F day and night.	70°F day/68°F night.	68°F day/55°F night.
Air Conditioning			
1. Improved insulation			
2. Improved efficiency - new air conditioners	All factors result in 46% savings for 1985 and 2000.	Savings increase to 56% for 1985 and 61% for 2000.	Savings increase to 61% for 1985 and 71% for 2000.
3. Higher thermostat levels			
- Water Heating			
1. Improved efficiency and insulation of of new water heaters.	NONE	5% more efficient in 1985 and 10% in 2000 for gas and oil heaters. 5% improvement in electric heaters in 2000.	10% more efficient in 1985 and 15% in 2000 for gas and oil heaters. Electric heaters same as moderate case.
2. Use of solar energy for water heating	NONE	Supplies 35% of hot water demand for housing built between 1985 and 2000.	Supplies 20% of demand for housing built between 1972 and 1985 and 70% for housing built between 1985 and 2000.
- Cooking			
1. Improved efficiency of ovens - microwave ovens, etc.	NONE	10% savings in 1985 and 2000.	25% savings in 1985 and 2000.
- Lighting and Miscellaneous Electric			
1. Improved efficiency - fluorescent lights, etc.	NONE	5% for 1985 and 2000.	10% for 1985 and 2000.
COMMERCIAL - Space Heating, Cooling and Lighting			
1. Reduced demand in existing buildings - lowered thermostats, improved operating procedures, reduced lighting levels.	15% reduction in average demand of all existing buildings for 1985 and 2000 for heating and 10% for cooling.	20% reduction in demand for 1985 and 2000.	25% reduction in demand for 1985 and 35% reduction for 2000.
2. Improved efficiencies in new buildings - air conditioning, total energy systems, lighting levels, etc.	Same as for existing buildings above.	35% reduction in demand for 1985 and 2000.	50% reduction in demand for 1985 and 2000.
3. Space heating and water heating from solar energy.	NONE	Same criteria as for residential sector	None prior to 1985. After 1985, same criteria as for residential sector.

Source: Lee, BNL 50552.

them with the skills inherent in many of the supply "fixes" currently being discussed. For the Northeast, many of these new supply technologies imply the importation of labor, which certainly does not alleviate the unemployment problems of the region.

Conservation strategies are also the least destructive to the interregional terms of trade, so the Northeast could continue to grow in spite of the relatively high marginal price it pays for energy. If the employment effects of such policies are realized and terms of trade effects are negligible, then the real price of conservation is minimal. Further, as conservation policy options can be implemented via existing policy instruments, the administrative price of conservation is also minimized.

It should be noted that there are distinct benefits to be gained from regional collaboration in approaching these strategies. For example, common construction and appliance performance standards would allow the region's manufacturing enterprises to invest in modifications in their products and production processes with assurance of a substantial market.

5.2 Conservation and New Jersey's Natural Gas Shortage (D. Morell, J. Cecil)

The importance of conservation in the Northeast is no more apparent than in the natural gas sector, and many Northeastern states are facing severe shortages this winter. In view of this emerging problem, a detailed analysis of the natural gas situation in New Jersey was conducted by the RESP in 1976, with a report due for publication in February 1977 (BNL 22318).

In the later 1960's and early 1970's, well in advance of the "energy crisis" atmosphere induced by the Arab oil embargo during the winter of 1973-74, it began to be apparent to consumers and policy makers that the nation faced an emerging natural gas problem. Annual additions to proven U.S. gas reserves have declined annually since 1967, and since that date production of gas has exceeded additions to proven reserves in every year. Despite strong and even increasing demand for gas by residential, industrial and commercial customers across the country, total U.S. gas production reached its peak in 1973 at 22.7 trillion cubic feet (Tcf), and began to decline. By 1975, production had diminished nearly 14 percent, to 19.6 Tcf.

As a result, though interstate gas prices regulated by the Federal Power Commission (FPC) have increased substantially, particularly in 1976, gas supply restrictions have required sometimes-severe reductions in the amount of gas available to numerous "low priority" customers, primarily in the industrial sector. At the same time, gas uses in the intrastate market (i.e., within the gas-producing states themselves) where there is no federal regulation have continued unabated. By 1973, for example, these five states--Texas, California, Louisiana, Oklahoma and Kansas--were consuming fully 41.6 percent of the nation's total supply of natural gas, often in low-priority uses.*

These national restrictions on the availability of natural gas already have caused some serious difficulties in New Jersey, and the challenge to formulate optimal gas policies for the state seems likely to increase rather than diminish in the years ahead. Declines in the volumes of gas supplied to each of the state's four major gas utilities began to appear as early as 1970. In the three most recent years alone, total supplies of gas to New Jersey have fallen from 321 billion cubic feet (Bcf) to 276 Bcf. The principal interstate pipelines serving the state have been forced to cope with curtailments well in excess of the national average of 18.7 percent for all pipelines. Transcontinental Gas Pipeline Company, for example, which will provide over 56 percent of New Jersey's pipeline gas supplies in 1975-76, faces a national curtailment of over 36 percent of its total supply volume.

No state in the nation, in fact, has a gas shortage greater than New Jersey's in terms of <u>both</u> volume and percentage of curtailments. Some have lost a greater volume of gas; others have faced larger percentage curtailments--but none rank higher in both categories.

The state's access to gas seems likely to get worse rather than better for at least the remainder of the 1970's. Industrial consumers already face serious deleterious impacts, and even residential consumers (the highest priority under FPC regulations) would be threatened in the event of a cold winter.

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*Natural gas consumer per capita in 1973 was 10.4 times as high in Louisiana as in New Jersey, and per manufacturing employee it was 24.2 times as high.

As detailed in our study, the net effects of this shortage on New Jersey's gas consumers vary widely between geographic areas of the state, types of consumers and end-uses of the gas. Customers with firm contracts for gas have been protected so far, though often only through provision of high-cost supplemental gas supplies. Consumers with interruptible contracts, however--primarily industries--have been cut off for periods ranging from a few days to as long as eight months.

The impacts of this gas shortage in New Jersey are particularly ominous because natural gas is the state's second-most-important energy source. In 1972, the state consumed 2.01 quadrillion Btu's of energy in all forms. As shown in Figure 7, natural gas provided 28 percent of this energy, second only to petroleum at 68 percent. Although the contribution made by natural gas at the national level was somewhat greater than in New Jersey, these data include the massive consumption in the intrastate gas market. The importance of gas to New Jersey is related to the fact that the state must rely on high-priced petroleum for its fuel oil needs, receiving only minute amounts of energy from all other sources (4 percent in New Jersey vice 22 percent in the nation as a whole).

Statements based on aggregate state data on sources and uses of fuel, however, provide little basis for formulation of effective public policies. Rather, the significance of natural gas as an energy resource varies according to consuming sectors, and it is at this level of disaggregation--if not below--that public policies must be devised and then implemented if the adverse affects of the gas shortage are to be ameliorated. New Jersey's industrial sector is particularly vulnerable to the natural gas shortage because of its heavy reliance on interruptible contracts, and because national curtailment regulations place lowest priority on industrial uses of gas. Because of these peculiarities, the industrial sector's vulnerability is not reflected accurately by the sector's 17.5 percent reliance on natural gas for its energy and feedstock needs in 1972,* in contrast to the residential and commercial sectors which used gas for 30 percent and 34 percent of their respective total energy consumption.

*This does not include natural gas liquids, examined only briefly in this report as they are quite distinct from natural gas (methane).

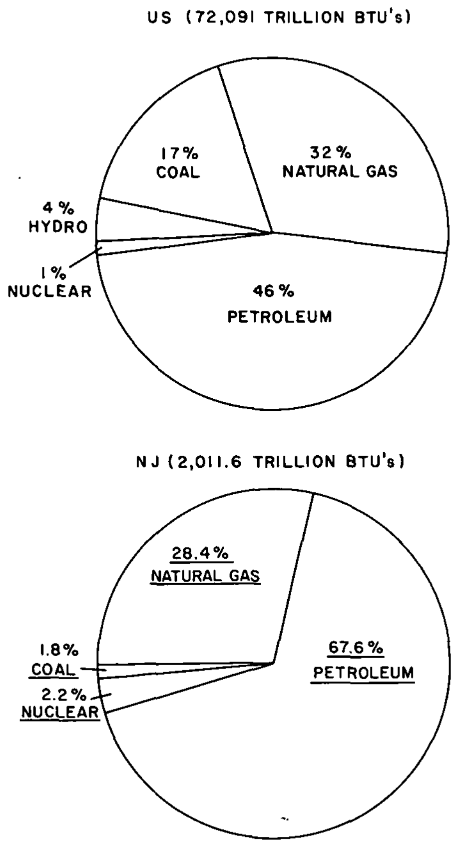

Figure 7. Comparison of national & state energy consumption by fuel 1972.

A number of policy recommendations emerged from our analysis. First, the state should attempt to expand interstate gas supplies, thereby making the gas more available to the state; this suggestion leads into analysis of the deregulation controversy. Second, New Jersey can try to increase its share of the amount of interstate gas, primarily through implementation of priority allocation schemes within the state.

Third, and more amenable to state actions alone, New Jersey can expand the availability of the supplemental gas supplies to the state. Increased reliance on liquefied natural gas, LNG, is one possibility although caution is urged because this source of supply from Algeria might easily be subject to a mid-winter embargo. Another possibility involves greater production of synthetic natural gas, SNG, within the state, although here the high costs are the principal worry. A third possibility is expanded production of refinery gas, now made available only to Public Service Electric and Gas

Company (PSE&G), and only from an Exxon refinery in Linden, New Jersey. Last year PSE&G obtained 11 bcf of gas from this source more than from any other supplemental source. Since New Jersey contains fully 34% of the total petroleum refining capacity on the entire East Coast, our analysis suggest the possibility that much more refinery gas might be made available to the state's gas utilities at a price far cheaper than LNG or SNG.

Another and very important set of strategies available to New Jersey in its efforts to lessen the impacts of the gas shortage, are aimed not at increasing supplies but rather at decreasing demand. One specific recommendation is to implement a statewide program to eliminate gas waste in continuous pilot lights which now account for over 8% of the state's total consumption of this valuable fuel. It is recommended that the 4 gas utilities be required by the Public Utility Commission to establish programs to replace existing pilot lights with electric starters to be repaid by consumers over several years on their utility bills (in lieu of the price savings from using less gas). After this relatively modest investment has been repaid in full, consumer bills would drop to reflect the savings in gas while from the beginning all this gas would be available for high priority uses within the state. A number of other specific gas conservation measures are also recommended for adoption within New Jersey.

Finally a series of short-term steps designed to cope with the immediate crisis by maximizing the uses of gas within the state are indicated. These include measures to allocate gas more efficiently within the state and to complement existing curtailment priorities through contract adjustments where justified--that is to make gas available to those users now operating under interuptible contracts where serious unemployment would otherwise result. In addition, a "lifeline" program is recommended to bring relief to those residential gas consumers who, living on a fixed or very low incomes, and faced with increasing gas costs, have difficulty paying the costs of even minimal amounts of gas for heating and cooking.

5.3 Current Work in Conservation

Whilst the Perspectives Study has pointed to the important contribution that conservation may make to the resolution of the region's energy problems, there is an obvious need to focus conservation analysis to a geographical scale consistent with political realities and institutional arrangements. We are thus in process of planning a study of conservation strategies in the New York City area, with particular emphasis on environmental consequences as well as energy system benefits. Using the urban and regional air quality models, discussed elsewhere in this report, the Load Management Model for the Consolidated Edison System (available at BNL by virtue of other ongoing work for FEA), the air emissions and air quality data bases available for the New York area, the results of conservation related studies now emerging from other ERDA sponsored research efforts, and the Reference Energy System as the energy accounting framework (as developed in earlier work by BNL and SUNY-Stony Brook)*, the study will focus on the assembly of an assessment tool appropriate to the analysis of specific policy measures in the city. In later stages the methodology will be generalized to other urban areas, with the ultimate objective of developing a handbook for use by urban and regional planning agencies.

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*See e.g. H.G. Jones, P.F. Palmedo and R. Nathans "Characteristics of Energy Use in the New York City Region" BNL 18880, May 1974 or M. Dohan and P.F. Palmedo "The Effect of Specific Energy Uses on Air Pollutant Emissions in New York City" BNL 19064, Sept. 1974.

VI. ENERGY FACILITY SITING

An important theme of the overall program is the siting of energy-related facilities. The intent is to develop regional scale assessment tools to evaluate all aspects--environmental, economic, socio-political, etc.--of particular siting options. In the BNL program the initial focus was on three siting-related issues: energy centers for nuclear and fossil plants, an evaluation of regional-scale siting methodology and the establishment of criteria for future electric power needs.

6.1 Energy Center Assessment (P. Meier, D. Morell*, W. Isard,+ R. Van Zele,+ Tom Reiner,+ F. Moore,# S. Linke#)

Our initial assessment of nuclear energy center siting, and particularly the evaluation of a surrogate site in New Jersey as part of the Nuclear Regulatory Commission's Nuclear Energy Center site survey, started in FY 75, was completed in early 1976. In addition to the New Jersey surrogate site analysis (BNL 50561), whose key results were summarized in the previous annual report (BNL 50478), 5 separate technical reports were completed in support of the policy analysis. These reports cover the regional economic impacts of both clustered and dispersed nuclear siting (with special emphasis on income and employment effects, colocation of industry and an input-output analysis of construction impacts: BNL 50562); an optimization analysis of water conveyance systems, important especially in the New Jersey surrogate analysis in view of significant distances between likely NEC sites and their sources of cooling water, even despite proximity to the Atlantic Coast: BNL 50563); An analysis of cooling tower noise (BNL 50564); and a detailed technical appraisal, including load flow analyses and the investigation of D.C. and IGC transmission, of transmission impacts (BNL 50565).

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Although our assessment of the New Jersey surrogate NEC site was unquestionably unfavorable, and although the overall NRC NEC Site Survey was rather ambivalent in its conclusions and policy recommendations,[2] we are not convinced that the concept should not be studied further. Certainly the key issue concerns not the technical feasibility of NEC's, but the degree to which they are acceptible to the public. To be sure, public reaction to the several NEC studies conducted in the United States over the past year has undoubtedly been quite negative[3], but there are powerful arguments that suggest that remotely located NEC's may be one of few ways to attaining a publicly acceptible energy system substantially dependant on nuclear energy, as the alternative of a proliferation of dispersed nuclear reactors around metropolitan areas, as is the current practice, may also be questioned on public acceptibility grounds. This latter point seems quite apparent from the recent rash of nuclear curtailment referenda throughout the country.

Thus it is our judgement that the concept of the nuclear energy center should be explored further, particularly from the standpoint of their relevance to the formulation of an effective national energy policy, to the issue of plutonium recycling, and to questions of inter-regional equity. We believe that these issues deserve a more widespread discussion in the technical community than has currently been the case, a goal to which we hope to contribute by the presentation of policy analyses at technical meetings. The first such paper, focussed on the relationship of energy center siting to demand uncertainty, and on the degree to which public perceptions on nuclear power might be affected by a cluster-siting policy, was presented at the 1976 ORSA/TIMS National Meeting (BNL 21205); other papers are in preparation.

6.2 Siting Model Development (P. Meier, J. Cohon,* D. Church+)

In the past decade, due at least in part to the passage of the National Environmental Policy Act that emphasized the necessity for demonstrating an environmental evaluation of alternatives, utilities and their

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consultants have made increasing use of mathematical modelling and computer techniques in the siting decision-process. In particular, so-called site screening and overlay techniques have become widely used by the Architect-Engineer consulting firms commonly retained by electric utilities for site selection advice and environmental evaluation. Although a recent review of these models[4] reveal some differences in the mechanics of the process (manual map overlays as opposed to computerized systems, differences in weighting criteria, and others), all are based on the common procedure of selecting candidate <u>areas</u> (10's to 100's of square miles) from candidate <u>regions</u> (100's to 1000's of square miles); subsequently defining candidate sites (1 to 10 square miles); and finally selecting sites by some weighting of evaluation criteria to yield potential and preferred sites.

Public agencies involved in the siting process have also shown interest in the development and use of such tools. At the Federal level, two of the ERDA Laboratories have on-going research programs emphasizing computerized siting methodologies based on the screening-weighting approach; The Regional and Urban Studies Department of Oak Ridge National Laboratory has developed a computerized site screening model for both nuclear and fossil facilities using the State of Maryland as a case study[5] and the Energy and Environmental Systems Division of Argonne National Laboratory has developed a somewhat simpler model called "SITE"[6]. And at the State Agency level, there are several examples of screening studies focussed on the identification and evaluation of power plant sites in a particular state.[7]

To what extent such site screening and overlay methods are appropriate for regional analysis, however, remains in some question. In regional scale energy policy analysis the focus is on the analysis and resolution of rather broad trade-offs; in regional siting analysis, for example, there is typically little emphasis on particular sites, but much concern with site categories (e.g. estuarine v. inland, clustered energy centers v. dispersed siting, load center v. mine-mouth, etc.) The study of such trade-offs is not easily handled with conventional approaches.

Another important shortcoming of the site screening approach is its limited ability to address adequately the problem of cumulative impact, due mainly to its inherent focus on the individual site and the environmental impact at that particular location. Even though a particular facility may be judged to have no significant impact on a particular resource at a particular site, a more pertinent question from the regional viewpoint concerns the cumulative impact of all facilities on that resource, not only those power facilities proposed for the short-term (which are within the focus of a site screening approach), but also all the facilities that might be proposed in the future, and including a consideration of the resource demands by other, competing uses (which are clearly beyond the capability of the site screening approach).

Yet, it is precisely this cumulative impact on a particular regional resource, over time and over all uses, that is of principal interest to the regional perspective. Thus to the regional policy analyst, the question of whether or not a particular proposed generating facility at a particular location will cause significant environmental impact is not nearly as important as the question of whether or not this facility is consistent with the optimum use of resources for power generation in the entire region. Thus, the regional perspective implies a longer temporal view than that necessary for the evaluation of a single project.

None of these arguments should be viewed as a criticism of site screening and evaluation techniques and their proponents, or indeed as a criticism of their utility. It is patent that the selection of specific sites is a very important part of the planning process, and the screening and overlay techniques now in use do represent a significant advance over methods less scientific. However, as a tool for regional policy analysis they would appear to require considerable extension.

The regional Energy Studies Programs at the ERDA National Laboratories, with their emphasis on regional energy policy issues, have suggested a number of alternative approaches to the development of siting models that are appropriate to the regional scale of analysis. At Oak Ridge National Laboratory a sophisticated approach based on political interaction analysis has been developed as an adjunct to their siting model, allowing resolution of regional siting issues in the context of a prediction of political feasibility[8]. And at Brookhaven, emphasis has been on the development of operations research approaches that could interface with the ensemble of energy systems analysis models resident at BNL's National Center for the Analysis of Energy Systems, and the regional environmental impact models at the BNL Atmospheric and Oceanographic Sciences divisions[9].

As an initial step in the development of such an operations research approach to regional siting policy analysis, an exploratory analysis of two areas of inquiry that appear especially promising was undertaken during the past year. The first rests on the application to siting of location theory, an area of inquiry that has seen a strong resurgence in the recent mathematical geography and regional economics literature as a result of its ability to address a rather large number of facility planning problems, in both the private and public sectors. The second such area of inquiry is multi-objective programming, a formalization of the notion that siting decision-making is an adversery process, in which a resolution of conflicting objectives is the key issue. A comprehensive report on these topics, which also develops an analytical siting optimization framework based on a synthesis of the two approaches, details the results of this assessment (BNL 50567).

6.3 Load Forecasting Methodology (O. Carroll, R. Stern)

Traditional approaches to load forecasting for electric utilities are based primarily upon extrapolation of historic trends and consider the electric sector in isolation from other fuel forms. Within such forecasts, it is difficult to identify specific impacts of conservation new technology, or fuel substitution, both in terms of maximum potential increase or decrease in the demand for electricity and the likelihood that such shifts in the demand for electricity will be realized.

Recognizing that the traditional approach must be reassessed, the Long Island Lighting Company (LILCO) contracted with BNL to establish a new methodology for load forecasting and to prepare independent forecasts of the demand for electricity in the LILCO service area. The method includes three specific objectives. First are:

1. Demand for electricity should be placed in a total energy perspective so that substitutions between electricity and other fuels can be examined.

2. Assess the impact of conservation, new technology, gas curtailment, and other factors upon demand for electricity.

A detailed analysis of changing levels of demand for electricity, and other fuels, associated with these new developments is founded upon a disaggregated end use characterization of energy utilitization, including space heat, lighting process energy, etc., coupled to basic driving forces for future demand which are population, housing mix, and economic growth in the region. The range of future events covers conservation, heat pumps, solar systems, storage resistance heaters, electric vehicles, extension of electrified rail, total energy systems, and gas curtailment. Based upon cost and other elements of the competition between technologies we assess the likelihood of these future developments. An optimistic view toward conservation leads to "low" electricity demands, whereas rapid development of new technologies suggests "high" demand for electricity.

While many emerging technologies, such as the heat pump, represent total energy savings or particularly savings in natural gas and oil utilization, they shift demand toward increasing market shares for electricity. The market share for electricity in the LILCO service area is expected to increase from 8% at present to about 18% in the year 2000.

Although the construction of the disaggregated forecast clarifies future developments and their individual contributions to demand, the method lacks an important perspective critical to the utility planning function. Though a future scenario can be identified which leads to a large demand for electricity, how likely is it that demand will reach, or indeed exceed, this level? Ideally, planning will be founded upon probabilities that given levels of demand for electricity will be realized. Consequently, our third objective is:

3. Construction of the probability distribution of the demand for electricity.

Our approach has been to establish approximate probabilities for conservation measures and new technology and combine these into cumulative probability distributions for selected years. The results yield distributions skewed to the low side in the short-run, reflecting likely conservation but little new technology, and skewed to the high side in the long-run. More importantly there are substantial probabilities (20-30%) of demand for electricity exceeding the upper bounds of a traditional utility forecast of "high" demand.

Two final points are in order. First, this study was limited to an annual requirement forecast. However, new technologies such as the heat pump, storage resistance heater, etc. - often may have very different load profiles from devices currently utilized. In some instances, the potential impact upon peak load forecasts may outweigh the effects upon annual requirements, and load implications certainly deserve detailed study to complete the projection of future LILCO system electric loads.

Second, this method of energy demand projection is not fully evolved. The basic concepts are established and the resulting forecasts are as valid as any for the region and considerably more enlightening with respect to detailed elements of future electricity demands. However, the method will benefit from greater input from econometric analysis. In addition, the social and utility investment costs associated with under and over-estimating electricity demand would be useful in establishing the sensitivity of capacity expansion planning to the probability distribution.

6.4 Current Work in Siting (FY 77)

Current work in the siting area is focused on the implementation of the regional siting model approaches discussed above, and the integration of these models into the overall regional assessment capability. This work will be conducted as a part of the National Coal Utilization Assessment (see below, Section 8.4), and has as its focus the analysis of siting policy and siting trade-offs as a function of increased coal utilization in the region. For example, as part of the air quality-health impact assessment that is one of the key components of the BNL NCUA work plan (see also Section 8.2, below), the siting model will be used to generate siting scenarios that in turn serve as inputs to regional air quality models, and will thus allow the examination of air quality and health impacts as an explicit function of siting strategies (mine-mouth v. load center, dispersed v. clustered, etc.)

At the time of writing, three linear programming siting models are available, one each for the major power pools in the region. They are interfaced directly with the multi-regional energy system optimization model discussed in Section 4.2, and have as their principal objective the allocation of electric generation capacity to the county level given specific environmental and land use constraints (consumptive water use restrictions, air quality restrictions, land use exclusions, etc.). Figure 8 indicates the elements of the analytical approach. The decision to implement three separate models was mandated by the necessity to incorporate the technical characteristics and constraints of the electric system into the siting model, and the recognition that long-range planning in the electric sector is likely to be performed on a power pool basis for some time to come. A technical report on the BNL Siting Model is in preparation.

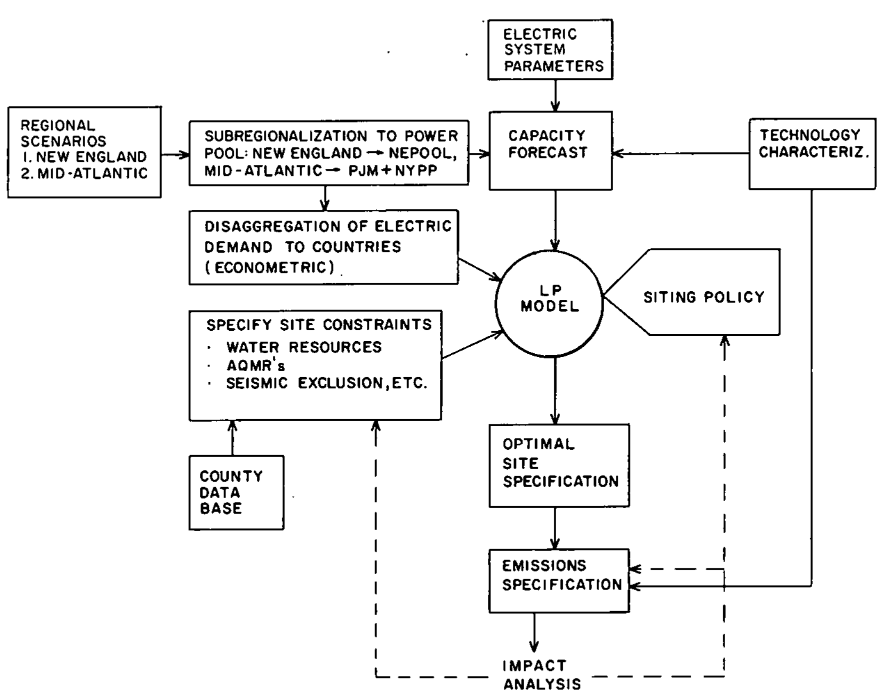

Figure 8. Siting analysis.

NOTES TO SECTION VI

1. Siting issues related to offshore development are discussed in Section IX.

2. See NRC Nuclear Energy Center Site Survey, Report NUREG-0001, Executive Summary, which notes "....the site survey supports the conclusion that it can be feasible and practicable, depending on location, to construct up to 20 nuclear power reactors on a single site. However, it does not indicate any great or unequivocal advantage or compelling need for such centers," p. 2.

3. In addition to the public controversy engendered in New Jersey as a result of the NRC study, public reaction to a utility group study of energy centers in Pennsylvania was quite vehement.

4. E. Graf-Webster, "Methodologies for Power Plant Siting" Report by the MITRE Corporation to U.S. Geological Survey, #M75-19, Feb. 1975.

5. S.L. Yaffee, and C.A. Miller, "Toward a Regional Power Plant Siting Method; AEC-Maryland Regional Siting Factors Study", Regional and Urban Studies Department, Oak Ridge National Laboratory, FY 74 Progress Report, Nov. 1974.

6. Frigerio et al, "SITE: A Methodology for Assessment of Energy Facility Siting Patterns" Argonne National Laboratory, Report ANL/AA-2, Aug. 1975.

7. New York State Public Service Commission, "Generating Station Site Survey", Draft Report on the Hudson River Valley/Long Island Pilot Area Site Survey, July 1974.

8. S.L. Yaffee, "Simulation and Analysis of Political Interation in Regional Systems" Oak Ridge National Laboratory, Report ORNL/RUS-23, July 1976.

9. P. Meier, "Energy Facility Location: A Regional Viewpoint" Brookhaven National Laboratory, Report BNL 20435, Aug. 1975.

VII. URBAN ENERGY SYSTEMS ANALYSIS AND ASSESSMENT

A large fraction of the population of the Northeast lives in or near the major cities: Boston, New York, Philadelphia, Washington and others. Besides this inate importance, the impact of energy use in cities is of particular importance because of the high density of receptors subjected to any energy generated residual, for example, air pollutants. At the same time, the large number of constraints on urban development (e.g., land availability) adds considerable difficulty to the job of finding acceptable urban energy supply technologies. This task aims eventually at an evaluation framework in which various options for urban energy supply can be assessed.

Working toward this assessment capability, the emphasis in FY 1976 was in the preparation and assembly of some of the basic building blocks of the ultimately desired methodology. The central component is an air quality model designed especially for application to urban areas, and for integration with the regional scale atmospheric transport models discussed in Chapter VIII of this report. Effort was also devoted to the modelling and projection of urban population distributions, an essential ingredient of subsequent computations and assessments of health impacts.

Assembly of the complete urban assessment methodology is currently underway in preparation for a study of the environmental impacts of conservation strategies in an urban energy system (described in section 5.3 above). Because of considerable previous work in the New York City area, especially the availability of detailed emissions inventories and information on the Consolidated Edison System, this urban area is being used as the case study area for model development and verification.

7.1 Urban Air Quality Modelling (C. Dopazo) The need for an air quality model designed especially for application to urban areas emerges from a number of considerations. Several recent publications show unequivocally that urban atmospheres are entities with physical and chemical dynamics of their own. A few of the peculiar phenomena occurring in an urban environment are:

Urban heat island effects: energy fluxes over an urban area are significantly modified; moreover, furnace heating provides an important energy input. Temperature inversions at elevations of 300 meters have been frequently observed over New York City area in nighttime hours, when the inversion was at ground level in the surrounding rural areas. The nighttime urban stability is consequently reduced in comparison to the rural.

Urban humidity patterns: As a consequence of the heat island effect the humidity profiles in an urban atmosphere are very different from those over the surrounding rural terrain.

Acceleration-deceleration effects over urban areas: It has been recently found that, due to the large value of the urban surface roughness parameter, as compared with that of rural areas, and for rural wind speeds above 8 mph for daytime and 9 mph for nighttime, the flow over a city is decelerated with respect to the air flow in the surrounding rural terrain. Below these critical speeds, and due to the predominance of the heat island effect, the same flow is accelerated over urban surfaces.

Wind direction changes over urban areas: Cyclonic and anticyclonic turnings of the rural air flow impinging on an urban environment have been analyzed. Changes in wind directions may be as large as 24° for a given hourly map of streamline flow and isotachs. Changes of wind direction of 180° have also been observed occurring in time intervals of six hours.

Sea breeze effects: The N.Y. City urban surface usually studied is composed of about 30% water, 60% open country and 10% built-up urban or suburban land. Sea and land breezes are familiar phenomena over this area. Dieterle and Tingle[1] have shown that pollutants released near the land-water separating line may flow inland due to the sea breeze. Under light wind episodic conditions recirculation may keep the contaminant within the urban boundaries for long periods of time.

Effects on transport and diffusion: Urban air pollution studies usually assume a unique mean wind speed, measured at a nearby airport, characterizing the entire urban area. Gaussian plume wind-rose models cannot incorporate any of the above realistic and well documented features. A method incorporating most of the above effects is presented by Johnson and Bornstein[2];

the real trajectories of a released puff as it goes through the city is calculated and the dispersion is estimated based on the real time of flight; comparison with the single airport speed for the entire area shows that the results may be far off, both spatially and temporally.

Dynamics of the urban inversion: Observation of the variations in mixing height are scarce both at the regional and urban scales. Tennekes[3] (and references therein) shows that the mixing height is a very important parameter and methods are being developed to predict it as part of the integral air pollution model. Meyers and Cederwall[4] have performed some sensitivity analyses to mixing height and are developing a new model capable of predicting it at the regional scale. A more spatially refined method for urban areas should be adapted.

Persistence of urban pollution: Tennekes[5] has recently shown using a simple box model that emission control strategies must be anticipated for them to have any beneficial impact during episodes. An important ingredient in his model is the mixing height, which is predicted using a simple model.

Downstream evolution of urban plumes: The plume from St. Louis has been observed by Wilson, et al,[6]; ozone and particulates were measured for distances of up to 200 Km downwind. Lyons and Rubin[7] have recently presented aircraft measurements of the Chicago urban plume at 100 Km downwind. This shows that the urban plume apart from its local effects has also a long distance impact to be considered in a regional long range transport-diffusion model. Shea and Auer[8] have qualitatively described the effect of summer-time mixing layer anomalies over and downwind of St. Louis upon odors, ice and Aitken nuclei, visibility, mixing height, turbulence, temperature and humidity.

Flow convergence over an urban area: SethuRaman and Cermak [9] found that the streamline flow over a city model in a large wind tunnel converge due to the heat island effect. Some observations of this effect have been reported recently.

Urban effects on precipitation patterns: This feature is of transcendental importance if the rainout and washout mechanisms, and consequently, a realistic removal estimate, are to be included in the model. N.Y. City has a very high rain rate. The change in rain patterns over an urban area as compared with a rural one may be due to the heat island effect. Meyers and Cederwall[10] treat the precis on rainout and washout for the regional long range transport model.

The objective, then, of the RESP modelling activity in this area is the ability to predict air pollutant concentrations in an urban area as a function of key variables typically encountered in policy assessment. Given the substantial air emissions and air quality information available for the New York City area, our approach has been to use this region for the development of the assessment models.

The comparison of the various predictive models is central to our task. In the near future one should be able to answer questions such as: For a well posed problem which is the most efficient model available? (in terms of both cost and accuracy) Are finite difference methods indispensible to obtain reliable information? What are the limitations of our models and can one live with them?

The validation of model predictions against measured air quality data also constitute an important part of the study. However, it is the isolation of the basic features of the phenomena, both physical and chemical, and an efficient combination of them, that is the major goal, rather than the participation in the illusory pseudo-scientific game of fitting data (the certainty of which is sometimes taken for granted).

During this initial period of acquisition and examination of the source emission inventory and the different wind roses available for New York City, exploratory runs using a model-city with prescribed point and area source and wind rose meteorology were conducted. These simulations have resulted in the understanding of some basic important features of the model.

In a comparison of the Gaussian plume and the Lebedeff-Hameed models to square area sources of 2 miles * 2 miles, using single wind direction and several wind speeds and stability classes, the latter was shown to yield concentrations between 2 and 6 times larger than those yielded by the Gaussian model.

A model city with four power plants was used in the remaining computations, comprising a total area of 60 Km * 60 Km; a central section of 20 Km * 20 Km, with large emissions and eight suburban squares, also 20 Km * 20 Km, but with much smaller emissions. Four oil-fired power plants are located in the periphery of the central section and the periphery of the suburban area (although the characteristics and location of the power plants and the area sources can be changed at will). A BNL wind rose is used to define the wind patterns.

One investigation was made of the differences in calculated concentration from different methods of subdividing regions into smaller source areas. It was found that for a small number of unit areas the differences may be substantial.

A further investigation concerned the relative contribution of point and area sources. These investigations were designed to yield qualitative and quantitative answers to the questions of whether burning oil with higher sulfur content or coal in power plants within the city boundaries would produce a significant environmental impact. In the example tested, it was found that a few kilometers from the center of the city the contribution of the elevated point sources may be as large as 20% to 30% of the total.

The sensitivity of the model to the effective heights of emission for area sources is also being considered. Preliminary runs seem to indicate that the effective height is an important parameter (differences as large as 50% in maximum concentrations have been obtained) and crucial in the determination of the relative contribution of point and area sources.

Finally, we have examined the sensitivity of the analysis to power plant location. For small changes in plant location and long-term predictions most receptor points experience very small changes compared with the previous point source location calculations. A few receptors, however, may experience large changes (50%). In any event, the changes in the total pollution levels are negligible. These peculiar effects for long-term calculations may be attributed to two causes; first, the relatively small contribution from the particular point sources to the total in the runs we have done and, second, the compensating effects of averaging over-all wind directions. In contrast, for short term calculations positional errors for point sources seem to have larger effects, i.e., small positional errors produce large deviations in the predictions.

Currently, emphasis is on developing an operational version for the New York City area. This will form the basis for the conservation-environmental impact study discussed in Section 5.3.

7.2. Urban Population Modelling (P. Meier, M. McCoy)

A number of research efforts in the regional studies program require analysis and projection of population distribution--notably the preliminary assessment of health impacts associated with increased levels of coal utilization (which requires population projections at the county level for the scenario years), the Perspectives Study analysis of solid waste utilization (which required analysis of the trade-off between refuse haul cost, a function of population distribution in urban areas, and the economies of scale of refuse energy conversion plants), and the spatial representation of electric demand in the residential sector for use in the siting model, also largely a function of the distribution of population. The methodologies developed for these purposes are reported in three documents: BNL 20916 ("An Analytical Approach to the Determination of Urban Population Density Gradients and its Application to Energy Planning Problem); BNL-National Coal Utilization Assessment Working Paper #3 (" A Methodology for Disaggregating OBERS Population Projections to the County Level"), and a paper presented at the EPA Symposium on Environmental Modelling and Simulation in April 1975 ("A Stochastic Model for Subregional Population Projection," BNL 20520).

REFERENCES TO SECTION VII

1. D.A. Dieterle and A.G. Tingle, "A Numerical Study of Mesoscale Transport of Air Pollutants in Sea Breeze Circulations", (1976), 3rd Symposium on Atmospheric Turbulence, Diffusion and Air Quality, Raleigh, N.C.

2. D.S. Johnson and R.D. Bornstein, "Urban-Rural Wind Velocity Differences in New York City and Their Effect on the Transport and Dispersion of Pollutants", (1976), prepared for Meteor. Prog., NSF.

3. H. Tennekes, "Observations on the Dynamics and Statistics of Simple Box Models with a Variable Inversion Lid", (1976), 3rd Symp. Atm. Turb. Diff. and Air Quality, Raleigh, N.C.

4. R.E. Meyers, and R.T. Cederwall "Transport and Diffusion using a Diagnostic Mesoscale Model Employing Mass and Total Energy Conservation Constraints", (1976), 3rd Symp. on Atm. Turb., Diff., and Air Quality, Raleigh, N.C.

5. Tennekes, note 3, supra.

6. W.E. Wilson, et al., "Characterization of Urban Plumes", (1976), 3rd Symp. Atm. Turb., Diff. and Air Quality, Raleigh, N.C.

7. W.A. Lyons and E.M. Rubin "Aircraft Measurements of the Chicago Urban Plume at 100 Km Downwind", (1976), 3rd Symp. on Atm. Turb., Diff. and Air Quality, Raleigh, N.C.

8. D.M. Shea and A.H. Auer, "Observations of the Regional Influence on Thermodynamic Properties and Aerosol Patterns in the Plume Downwind of St. Louis", (1976), 3rd Symp. on Atm. Turb. Diff. and Air Quality, Raleigh, N.C.

9. S. SethuRamon and J.E. Cermak "Physical Modelling of Flow and Diffusion over an Urban Heat Island" Adv. Geophysics, Vol. 18, p. 223-240 (1974).

10. R.E. Meyers and R.T. Cederwall "New Technique to Help Determine the Acid Rain Impact upon the Ecology of the Eastern United States," (1975), in Atmospheric Sciences Annual Progress Report, 1974, W.D. Tucker, Ed., BNL 50485.

VIII. INCREASED USE OF COAL IN THE NORTHEAST

The analysis and policy assessment of increased coal utilization in the Northeast continues to be one of the main themes of the BNL regional studies program. In the past, considerable emphasis was devoted to the development of models appropriate to regional scale assessment of environmental and health impacts resulting from coal combustion, continuing efforts that are the subject of sections 8.1 and 8.2, below.

The analysis of future coal utilization was also a key ingredient of the Northeast Perspectives Study (see section 2.1, above), and a separate technical report (BNL 50560) presents an assessment of the potential contribution of coal to the region's energy system, as well as a preliminary investigation of the key constraints to coal use in the Northeast. Work was also initiated in the characterization of coal technologies, in the recognition that credible environmental assessments depend crucially on the specification of polutant emissions. This work, designed to interface directly with the air quality and siting models, is described in section 8.3.

All of these efforts are of course directly applicable to the National Coal Utilization Assessment (NCUA), a coordinated assessment program currently underway at each of the national laboratories' regional studies programs that seeks to develop an integrated national perspective of the environmental impacts of increased coal utilization from a series of regionally sensitive assessments. This study, discussed in section 8.4, is the subject of a separate, detailed Program Plan, to be published shortly.

8.1 Atmospheric Pollutant Transport (R. Meyers, R. Cederwall)

In our previous annual report (BNL 50478) we dealt at some length with the development of a trajectory-diffusion model for the study of regional atmospheric pollutant transport phenomena, a model that continued to be refined and tested in the current year, particularly as preparation for the current study of sulfate problems as part of the National Coal Utilization Assessment. This model has also been used in the current year in connection with the analysis of regional ozone problems, analyses that were published in a series of conference presentations and journal articles. (See Appendix, Section III).

In assessing the impact of fossil energy upon air quality considerable attention must be paid to ozone. Ozone levels are regulated by the EPA since high levels are known to have deleterious health effects. Net tropospheric ozone comes from several processes. It may be injected from the stratosphere where sunlight produces large amounts, or it may be produced in the troposphere by photochemical processes involving among other things hydrocarbons and nitrogen oxides. The connection to the use of fossil fuel would appear to be evident since power plants emit large amounts of nitrogen oxides. Since EPA standards and more importantly prudent levels are often exceeded throughout the U.S., especially in the Northeast, it is incumbent upon energy planners to determine the fraction of total ozone derived from energy sources, and to this end a number of studies were conducted in cooperation with Northeastern State Agencies. The first analyses the contribution of stratospheric injection of ozone into the Northeastern United States troposphere. The second observes and tracks, using BNL trajectory methods, high concentration ozone fronts through the states of Connecticut, New Jersey and New York during two ozone episodes. And the third study shows the regional impact of ozone in a 19-state study wherein long-range transport of photochemical air masses is observed across the Midwestern and Eastern United States. All three of these studies used data taken by the state agencies and the trajectory methods developed by the RESP in previous years (see e.g. BNL 50478, p. 49-51 and Appendix A).

Ozone Transport from Stratosphere to Troposphere: Ozone in concentrations exceeding the U.S. Environmental Protection Agency's national ambient air quality standard (80 parts per billion, hourly average) has been measured frequently in remote areas of the United States. Such occurrences are regional and seasonal, associated with high-pressure weather systems during the summer months[1]. Peak ozone concentrations are generally observed on the back or stagnant side of the high-pressure system, where conditions may also be ideal for lower tropospheric ozone production through photochemical ractions involving NO_2 and both natural and man-made hydrocarbons.

A second source, the descending stratopsheric ozone, has also been proposed as a significant contributor to tropospheric ozone[2]. We have investigated this by using ^{7}Be as a natural tracer of stratospheric contributions to the troposphere at relatively isolated Whiteface Mountain, New York. Simultaneous measurements of ozone and ^{7}Be at this location in July, 1975 show that maximum ^{7}Be activities are accompanied by increased ozone concentrations. Since ^{7}Be is produced predominantly in the stratosphere, this relationship can be used to trace ozone of stratospheric origin. Isentropic trajectory calculations also showed the trajectories reaching Whiteface Mountain on July 11-12, 15-16, 23, and 27 had stratospheric origin. Peaks in ^{7}Be activity occurred on July 5-6, 11-12, 16-17, 23, and 27. Ozone peaks followed a day later. Stratospheric air affects surface ozone concentrations more on the stagnant side of the high-pressure system than on the subsidence side.

An Investigation of Long-Range Transport of Ozone Across the Midwestern and Eastern United States: A considerable amount of data suggesting the importance of long-range ozone transport has been generated over the past few years,[3] and several investigators have characterized ozone generation and subsequent transport within urban plumes.[4] Transport of this nature produces elevated concentrations downwind of the urban center and does not account for the high concentrations observed upwind of the urban plume source.

In 1976, Wolff et al showed the additive contributions of multiple urban plumes on ozone concentrations as air parcels traveled northeastward through the "Washington, D.C. - Boston, Mass. Corridor."[5] Prior to the onset of the southwesterly flow, the air parcels entering this corridor from the west already contained ozone concentrations in excess of 0.10 ppm. Since these levels could not be directly associated with any particular urban plume, they were assumed to be the background levels associated with the particular air parcels entering the "corridor." The data further indicated that the ozone levels associated with air parcels were dependent upon the previous path and rate of travel of the air parcels. Since trajectory analysis demonstrated that these parcels had passed over industrialized and urban areas of the midwest, it was suggested that the midwest could be a significant source region for the ozone observed entering the "corridor."

In order for significant transport from the Midwest to occur, three conditions must be met: elevated levels must exist in the Midwest, the air must be advected from the Midwest to the East Coast, and the ozone must persist in high concentrations overnight. The classical diurnal ozone pattern observed in urban and rural areas indicated that on the surface, at least, the rate of ozone depletion was such that long-range transport was not feasible. Observations by Stasiuk and Coffey[6] however, indicated that above the nocturnal inversion layer, the rate of ozone depletion was much less. Using data from vertical ozone profiles, Ripperton[7] estimated the ozone half-life above the nocturnal inversion layer to be approximately 29 hours. Based on the Da Vinci experiment, Ripperton[8] calculated a half-life between 15-30 hours in the dark. With a half-life on this order it is possible for long-range transport to occur. Thus our analysis examined the ozone distribution in the Midwest and the Northeast and with the assistance of trajectory and meteorological analyses, assessed the importance of transport from the Midwest to the Northeast.

Anatomy of Two Ozone Transport Episodes in the Washington, D.C., to Boston Massachusetts, Corridor: The incidence of episodes of increased ozone levels in the northeastern United States has been studied extensively by the states of New York, New Jersey, and Connecticut and the Interstate Sanitation Commission for the past three years. Surface ozone data from New York, New Jersey and Connecticut during this period indicate that there are generally four or five such episodes per month from May through August. They generally persist for one to eight days, but 3 to 4 day episodes are the most frequent.[9]

These episodes are generally associated with a single air mass and terminate as a new air mass moves into the region[10]. Stations separated by hundreds of miles but under the influence of the same high pressure system (high) generally have similar ozone levels.[11] Studies have also indicated that the area of highest ozone within a high pressure system usually occurs in the southwestern or western sector of the high pressure system.[12] This is consistent with observations in the Northeast which indicate that highest ozone levels are reached when under the influence of southwest winds on the return flow around the high pressure system.[13]

On July 21 and August 18, 1975, cold fronts passed through the Northeast. With northwest flows prevailing on July 22, August 19 and 20, ozone levels were generally low (less than 80 ppb) over the entire region. However, on July 23 and August 21, the ozone levels increased dramatically even though this area was under the influence of the same high which persisted on the previous day. The purpose of the study was to characterize the changes in the meteorological parameters associated with these sharp increases in ozone levels, document the movement of the "ozone front" across the region, and employ trajectory analysis to determine possible source regions of the high ozone.

8.2 Atmospheric Chemistry (R. Adamowicz, F. Hill, R. Meyers, E. Ziegler, R. Cederwall)

Assessing the impact of atmospheric effluents from alternate energy strategies requires understanding of the physico-chemical transformations which ensue between the stack orifice and the ultimate receptor of the pollution. Early in the regional study we recognized that there had been no useful synthesis of these evolutionary processes which could shed quantitative light upon the potentially major ecological problem of "acid rain" and the health problem resulting from oxidation of SO_2 to sulfate.

8.2.1 Acid Rain

The "acid rain" is roughly defined as the problem of the formation of significant amounts of acid in rain drops resulting from industrial air pollution processes. The increased acidity in the rain would then have the ability to acidify the soil and the herbaceous material directly. Thus, in the Northeast, where there already exists a delicate balance of soil hydrogen ion content, species of flora, and climate, the productivity of the region could be greatly modified.

There currently wages a major scientific controversy in the open literature as to the evidence that the acid rain is yet a regional problem. Evidence seems to be more clear, however, that locally in the vicinity of power plants increased acidity of rainwater results from the washout of SO_2 from power plant emissions.

A long distance from power plants the SO_2 and NO_x emissions from power plants might have a significant impact upon the acidity of the rain through the process called rainout. Rainout occurs when nucleating water drops incorporate the power plant effluent in the cloud or raindrop formation process. This is contrasted with the process of washout where raindrops already formed pick up the effluents during their descent to the ground.

A number of studies conducted in the RESP have addressed different features of this problem so that our long-range objective of determining quantitatively the potential for acid rain impact of alternate energy technologies upon the ecology of the Northeast may be achieved. The following is a brief introduction to the acid rain studies completed or in progress in the BNL RESP program.

A Model for Rain Composition and the Washout of Sulfur Dioxide* (F.B. Hill and R.F. Adamowicz) The washout of sulfur dioxide from the atmosphere is a phenomenon which contributes to the production of so-called "acid rain"[14] and at the same time helps in the cleansing of the atmosphere. Effective models of the washout process are useful in predicting the composition of rain and the time scale for SO_2 removal. Two principal kinds of washout models have been devised in the past: physical models, exemplified by the work of Hales and his colleagues[15] and chemical models, stemming primarily from the work of Scott and Hobbs[16]. The physical models are mass transfer models in which the soluble gas is nominally regarded as inert but has a distribution coefficient which varies with SO_2 uptake, thereby taking into account in an approximate way the variation in hydrogen ion concentration which occurs as SO_2 dissolves in the falling rain drops. In the chemical models, mass transfer is taken to be infinitely rapid. Consequently, the composition of the falling rain is always in equilibrium with the concentration of SO_2 in the atmosphere, subject to the electroneutrality condition and to the extent of production of sulfate ion by oxidation of bisulfite and sulfite ion. In the present study, the two models were combined by modifying the mass transfer relation for an inert gas to incorporate

*Presented at the AICHE 69th Annual Meeting, Chicago, Ill., November 28-December 2, 1976. BNL-21794.

explicitly the ionic equilibria of the chemical model. The model which results allows for continuous variation of rain composition with fall distance. The model is used in illustrative fashion to calculate the composition of rain as a function of fall distance and to obtain the time scale for SO_2 removal from the atmosphere. A very simple chemical system is used as a basis for the model for the sake of ease of identification of the origin of effects predicted by the model.

Acid Rain Data in the Northeastern United States (E.N. Ziegler, R.E. Meyers, and R.T. Cederwall) The evidence for making the conclusion that acid rain in the northeast United States is a major problem has not yet been fully collated. Scattered data have been collected by many different agencies. Precipitation chemistry data is the most important. Unfortunately, these data have been obtained using many different techniques, some of which are highly suspect, and none of which are totally satisfactory.

Recently we have started a study to collect, collate, and analyze precipitation chemistry data in the Northeast in order to objectively focus upon the question of whether there yet exists hard evidence for concluding that acid rain is a regional problem. The first phase of the study has involved the establishment of a bibliography for precipitation chemistry data in the Northeast. In addition to performing a literature search, contact has been made with the appropriate state agency for each state in the Northeast. Table 7 lists the bibliography of primary precipitation chemistry data yet uncovered which will be investigated for increasing trends of acidity which might be ascribed to power production processes. A much larger list of secondary investigations of parts of these data is not included, but will be identified as the study reaches the analysis phase.

The ultimate goal will be to use it as a basis for assessment model verification. The BNL long-range transport model[17] already incorporates a rain washout module. This package will be modified for inclusion of the precipitation chemistry modules of Adamowicz and Hill and compared against the data scrutinized in the present study.

TABLE 7

Preliminary Bibliography of Acid Rain Measurements in Northeast United States

1. Connecticut
Yanosy, V. (1977): Personal Communication of pH Measurement from Air Monitoring Section (Connecticut State Health Department) Sept. 1974 - Feb. 1975.

2. Connecticut, Maine, New Hampshire, New York, Pennsylvania, Virginia, Vermont (Review of Older Data)
Pearson, F.J. and D.W. Fisher (1971): Chemical Composition of Atmospheric Precipitation in the Northeastern United States, Geological Survey Water - Supply Paper 1535 p. (Geochemistry of Water Series).

3. Maine and New Jersey
Environmental Data Service, 1976 "Atmospheric Turbidity and Precipitation Chemistry Data for the World", Annual Series, (data lags by two years).

4. Maryland
Li, T.Y. and H.E. Landsberg, (1975): Rainwater pH close to a major power plant, Atm. Env. 9, 81-88. Discussion 1975, Atm. Env. 9, 945.

5. Massachusetts
Silver, W., - Personal Communication of Geological Survey Data, Water Resources Division, U.S. Dept. of Interior (Boston) For Amherst, Mass. Oct. 1973 - Sept. 1974.

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A Model for the Reversible Washout of Sulfur Dioxide, Ammonia and Carbon Dioxide from a Polluted Atmosphere and the Production of Sulfates in Raindrops. (Robert F. Adamowicz and Frank B. Hill)

As with the preliminary model discussed above,[18] this model also incorporates detailed solution kinetics along with the fundamental microphysics of trace gas washout of sulfur dioxide. This model applies to the washout of an atmosphere containing sulfur dioxide, ammonia, carbon dioxide, and incorporates reversible mass transfer of the trace gases, all possible ionic equilibria of the compounds in solution and catalyzed oxidation of the dissolved sulfur species to sulfates.

The significance of ammonia and carbon dioxide on raindrop capacity for sulfur and on sulfate production based solely on bisulfite oxidation have been explored in detail. The influence of raindrop size, rainfall intensity, cloudbase height, the presence of oxidation catalyzing compounds in the atmosphere and the initial composition of the raindrops as they enter the polluted atmospheric layer on the detailed chemical composition of rain at ground level and the time scale for gaseous sulfur dioxide removal have also been evaluated.

Illustrative model simulations suggest that the chemical composition of rain is, in general, mass-transfer rate limited. Carbon dioxide was found to have little effect on the concentration transients or the approach to equilibrium composition of raindrops as they fall through the mixed layer. Ammonia, however, considerably increases rain's capacity for sulfur, as shown on Figure 9, and causes the chemical composition of even small droplets (light rainfalls) to be mass-transfer rate limited. In addition, the effect of a background non-volatile base (such as NaOH) on the transient composition of rain was found to be quite different than the effect of a volatile base (NH_3), giving rise to a step-function behavior of the transient pH and aqueous sulfur dioxide concentration. The presence of a non-volatile base in the atmosphere may be causitive to occurrence of a bimodal pH distribution in raindrop size spectra.

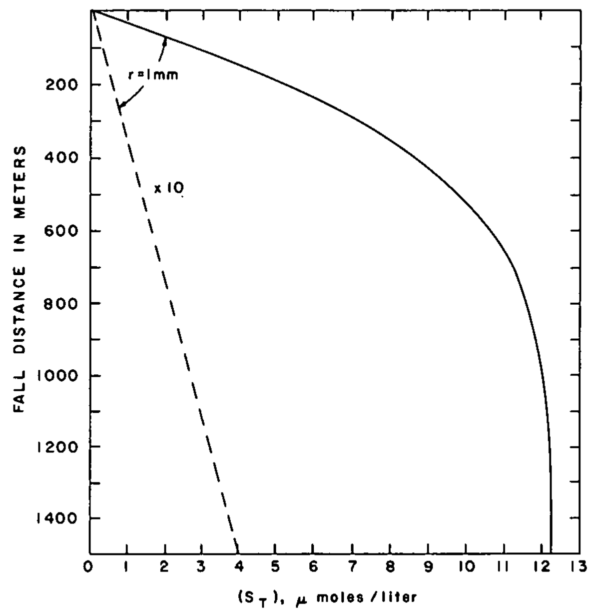

Figure 9. Total sulfur concentration in large raindrops vs. fall distance of the rain. $(SO_2)_g$ = 10 ppb, $(CO_2)_g$ = 320 ppm, $k_{HSO_3^-}$ = 0, and (A^-) = (M^+) = 0. Solid curves = 0 ppb $(NH_3)_g$; broken curves = 20 ppb $(NH_3)_g$.

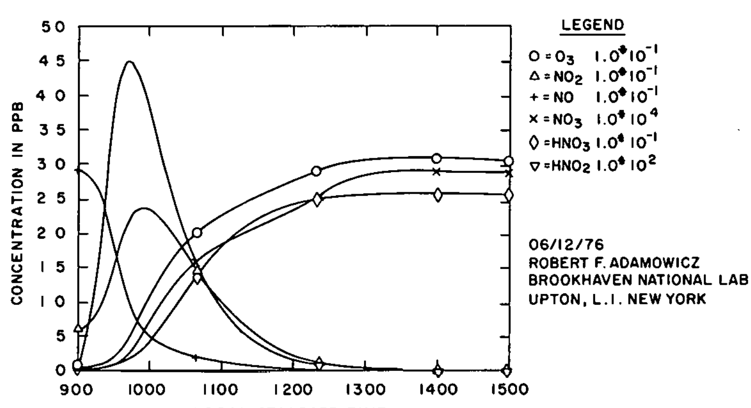

Figure 10. Kinetics simulation (New York City).

TABLE 8

Inventory of Reactions in Atmospheric Chemistry Model

Reaction #	Reactants		Products	Forward Rate Constant
1	NO_2	→	$NO + O$	.432
2	$O + O_2$	→	O_3	21.6
3	$O_3 + NO$	→	$NO_2 + O_2$	23.7
4	$O_3 + NO_2$	→	$O_2 + NO_3$	$.477 \times 10^{-1}$
5	$NO + NO_3$	→	$2\ NO_2$	12859.0
6	$NO_2 + NO_3 + H_2O$	→	$2\ HNO_3$	.10190
7	$NO + O$	→	NO_2	512.0
8	$NO_2 + O$	→	$NO + O_2$	13445.00
9	$NO_2 + O$	→	NO_3	2912.0
10	$NO_2 + NO + H_2O$	→	$2\ HNO_2$	.2200
11	HNO_2	→	$NO_2 + NO + H_2O$	$.1400 \times 10^{-2}$
12	HNO_2	→	$NO + OH$	$.1300 \times 10^{-1}$
13	$NO_2 + OH$	→	HNO_3	6000.00
14	$NO + OH$	→	HNO_2	266.00
15	$NO + HO_2$	→	$NO_2 + OH$	259.60
16	H_2O_2	→	$2OH$	$.1500 \times 10^{-2}$
17	O + OLEF.	→	$.5\ HO_2 + .5RCO_3 + RO_2$	6800
18	OH + OLEF.	→	$RCHO + RO_2$	25000
19	O_3 + OLEF.	→	$OH + RCO_3 + RCHO$	$.1100 \times 10^{-1}$
20	RCHO	→	PROD	$.25 \times 10^{-2}$
21	RCHO	→	$1.5\ HO_2 + .5RO_2$	$.2500 \times 10^{-2}$
22	OH + RCHO	→	$.5HO_2 + .5RCO_3$	23000.
23	$NO + RO_2$	→	$NO_2 + RO$	3000.
24	$NO + RCO_3$	→	$NO_2 + RO_2$	1500.0
25	$NO_2 + RCO_3$	→	PAN	500.0
26	$O_2 + RO$	→	$HO_2 + RCHO$	$.625 \times 10^{-2}$
27	$NO_2 + RO$	→	$RONO_2$	490.0
28	NO + RO	→	RONO	250.0
29	$2\ HO_2$	→	$O_2 + H_2O_2$	8280.0
30	$HO_2 + RO_2$	→	$O_2 + OH + RO$	100.
31	$2\ RO_2$	→	$O_2 + 2RO$	100.
32	$O_2 + OH + CO$	→	$HO_2 + CO_2$	$.122 \times 10^{-2}$
33	$O_3 + .060H_2O$	→	$.940\ O + O_2 + .120\ OH$	$.185 \times 10^{-5}$
34	$O + SO_2$	→	SO_3	116.80
35	$HO_2 + SO_2$	→	$OH + SO_3$	1.33
36	$H_2O + SO_3$	→	H_2SO_4	1340
37	$RCO_3 + SO_2$	→	$RO_2 + SO_3$	32.00
38	$RO_2 + SO_2$	→	$RO + SO_3$	.440
39	$RO + SO_2$	→	SPROD	4.40
40	$HO_2 + CO$	→	$OH + CO_2$	$.1478 \times 10^{-3}$
41	$OH + SO_2$	→	HSO_3	890.0

for sulfates. This study attempts to develop a correlation between daily averaged sulfate concentration and key meteorological and pollutant measurements. These correlated variables can then serve as candidate precursor indexes for inclusion in models for prediction of ambient sulfate levels due to energy generation.

One may predict regional ambient concentrations by developing the equations of component mass transport (diffusion equation) for typical meteorological source and chemical reaction situations. For linear reaction generation rates the solutions are well known. However, theoretical formulations of sulfate reactions appear non-linear and complicated.

As the overall oxidation reaction becomes more nonlinear, the computational approach of the diffusion equations becomes increasingly difficult to apply. Also, the kind and quantity of data available for verification is insufficient to test the model parameters. In order to simplify the analysis process we have resorted to the use of a semi-empirical lagrangian box model and nonlinear reaction kinetics to develop candidate relations for correlation testing against atmospheric meteorological and chemical monitoring data contained in the BNL data base.

A few empirical approaches have also been reported for finding the dependence of ambient sulphate on other atmospheric and pollutant variables. Prior to 1970 relatively little sulfate data were available at monitoring stations where other pollutant and meteorological data were collected. In studies since 1970, Altshuller[20] correlated nationwide urban site annual average sulfate values with SO_2 data and found that $[SO_4^{=}]$ followed the relationship

$$[SO_4^{=}] = 0.144[SO_2] + 4.92\ \mu g/m^3$$

when $[SO_2] < 20\ \mu g/m^3$ and was independent of $[SO_2]$ above that concentration. Sanbert[21] confirmed a dependence on SO_2 for the San Francisco Bay area, and found

$$[SO_4] = 0.08\ [SO_2] + 2.00\ \mu g/m^3$$

Future work will involve the incorporation of the washout model into the BNL transport model for assessment of influence of power production upon acid rain formation in the Northeast.

8.2.2. Homogenous and Heterogenous Chemical Reaction Modelling (R. Adamowicz, S. Schwartz, R. Meyers) The eventual product of this activity is a realistic chemical kinetic module for input to the BNL transport model used for impact assessment of fossil fuel utilizations. The first phase of this project has involved the development of several important analytical tools for computer analysis of the relevant chemical reaction kinetics. Among those tools that have been developed are 1) an integrator to interpete the large system of "stiff" (widely varying time constant) chemical reactions efficiently, 2) A program to handle chemical matrix notations, 3) A program to monitor individual chemical rates as a function of certain reactions and overall rates, useful to a kinetic analyst, and 4) a graphics package to increase the efficiency of data analysis. Figure 10 illustrates a simulation of photochemical oxidant evolution in New York City using these tools. In addition a preliminary atmospheric homogenous chemistry model has been developed which utilizes 41 reactions and up-to-date rate constants and includes SO_2 homogeous gas phase oxidation to sulfate. These are displayed in Table 8.

Future work will involve the analysis of these reactions in competition with heterogenous particle gas reaction involving SO_2 oxidation. These reactions will finally be lumped into fewer surrogate species which can be run and compared with data with the BNL transport model. Only then can we be confident as to the degree of the importance of the non-linear reactions in the projection of regional impact due to increased use of coal for energy.

8.2.3. Effects of Meteorological Variables and Chemical Precursors on Ambient Sulfate Concentrations (R.E. Meyers, E.N. Ziegler)

Particulates compounded with SO_2 and sulfate aerosol have been implicated as lung irritants and have been linked with pulmonary emphysema and lung cancer.[19] Sulfur containing aerosol is likely to be more toxic than comparable concentrations of sulfur dioxide. As a result, the U.S. Environmental Agency and others are currently considering "ambient" standards with all concentrations $[SO_4^=]$ <20 μg/m^3. Tong and coworkers[2] have analyzed data at 12 stations (40-45° Lat.) between Collins, Illinois and Albany, New York and concluded the following: (a) Means of daily averaged $[SO_4^=]$ values, taken over 5°CΔT intervals, increase with increase in ambient temperature, (b) means of daily averaged $[SO_4^=]$ values, taken over 5°CΔ dew point intervals, increase with increase in dew point. (c) $[SO_4^=]/[SO_2]$ ratios taken within 2 millibar Δp_{H_2O} intervals, increase sharply with increased ambient partial pressure of moisture. In a more recent study, Altshuller[23] reported the $[SO_4^=]$ varied much less from urban to nonurban areas (i.e., 2:1) than did $[SO_2]$ values i.e., 5^+:1). The mass median diameter was found to range between 0.2 and 1 m, with 80-90% of the aerosol below 2 μm.

In the present study daily ambient sulfate concentration data for 13 eastern states (U.S.A.), c_2, were related to sulfur dioxide concentration, c_1, particulate concentration, c_p, % relative humidity, H, temperature, T, and solar radiation, S. The ranges of basic variables studied were $3.8 < c_2 < 44.1$ μg/m^3, $0.0 < c_1 < 167.0$ μg/m^3, $22.0 < c_p < 377.0$ μg/m^3, $35.4 < H < 100\%$, $13 < T < 96°F$ and $0 < S < 12$ hrs. Briefly it was found that at low temperature, T < 50°F, c_2 was correlated with the product of c_1, c_p and H. At higher temperature, T > 50°F, higher correlation coefficients resulted when c_2 was related to c_p alone than when related to any other combination of variables tested. In addition to the data analysis, sulfate formation investigations concerning the mechanism of sulfate formation continue to be reviewed and interpreted in relation to atmospheric variables. A representative list of sulfate mechanisms investigated can be found in Table 9. Chemical constituents and properties of sulfates studied are listed in relation to the sulfate formation mechanism.

8.3 Technology Characterization (E. Rubin*)

Since environmental impact assessments of coal technolgies depend crucially on a credible specification of emissions, and since many of the coal related issues in the Northeast center on the trade-offs between air, water, and land residuals (witness, for example, utility resistance to FGD

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*Carnegie-Mellon University.

TABLE 9

Variables Required For $SO_4^=$ Formation Study (A Representative Sample of Investigations)

	Mechanism	References	Year	$SO_2(g)$	Temp	$NH_3(g)$	$SO_4^=$	Mean Drop Diam.	Drop Conc.	Drop Size Distr.	Humid	H^+	NH_4^+	HSO_2^-	HSO_4^-	SO_3^{2-}	$H\dot{O}_2$ or OH(g)	OH(l)	Hydro-Carbons	NO or NO_2	$SO_2(l)$	Mn^{2+}	Fe^{2+}	Fe^{3+}	H_2SO_4
1	Liq. Phase Diffusion Controls	Johnstone & Coughanwer	1958	X			X														X				
2	Iron Catalyzed Reaction	Junge & Ryan	1958	X		X	X					X	X					X				X	X		
3	Cat. Influence on Liq. Phase rate	Johnstone & Moll	1960				X		X		X											X	X		
4	Nucleation & Condensation Rates	Fletcher	1962					X	X	X	X														
5	Absorption & SO_2–$SO_4^=$ liq. phase reaction	Van Den Heuvel & Mason	1963	X		X	X	X													X				
6	Liq. Phase Oxidation Sulfite limits rate (See 16)	Scott & Hobbs	1967	X		X	X					X		X							X				
7	Smoke Plume Kinetics	Foster	1969	X			X	X			X											X			
8	4 Step Liq. Phase 1 Limiting	Matteson et al.	1969	X			X					X			X							X			
9	Absorb. of SO_2 & liq.ph.rate control	Cheng, et al	1971	X			X				X											X			
10	Photochem. quench of triplet molec.	Badcock et al.	1971	X													HO_2		RH						
11	Photolysis	Katz & Gale	1971	X				X	X		X								RH	NO_2					
12	Nucleation	Quon, et al.	1971	X				X	X	X	X		X									X		X	X
13	Free radical	Urone, et al.	1971	X							X								RH	NO_2					
14	Non-catal. rate depends on SO_2 solub.	McKay	1971	X	X	X	X						X	X		X		X			X				
15	Coagulation rate affect size dist.	Lindenmaier & Castleman	1971					X	X	X															
(16)	Free Radical	Urone, et al.	1968	X															RH	NO_2				X	
17	Free Radical	Timmons, et al	1971	X															RH						
18	Free Radical	Cox & Penkett	1971	X															RH						
19	Liquid Phase	Matteson, et al.	1972	X			X					X			X							X			
20	Equil. gas-liq. Neglect 2nd ioniz.	Hales & Sutter	1973	X	X							X		X		X									
21	Heterogeneous Solid Fe_2O_3	Glaun & Quon	1973	X							X													X	
22	Mixture Nucleation	Kiang, Mohnen, et al.	1973	X				X	X	X	X									HNO_3					X
23	Heteromolecular Nucleation & Growth	Stauffer, Mohnen, et al.	1973					X	X																X
24	Nucleation	Castleman	1973	X		X											OH								X
25	Photochemical HO_2 with SO_2	Davis, et al.	1973	X													HO_2								X
26	Ion Growth	Kadlecek	1974	X		X	X	X				X	X												
27	Iron catalysis various dependencies	Freiberg	1974	X	X	X	X	X	X		X	X	X			H_2SO_3 X					X				X
28	Photochemical Rates	Smith & Urone	1974	X			X												C_3H_6	NO & NO_2					
29	Growing, coagul. aerosol & reaction	Walden, et al.	1974	X				X	X	X	X		X									X			X
30	Binary nucleation $H_2SO_4 + H_2O$	Mirabel & Katz	1974			X		X	X	X	X		X							HNO_3					X
31	Various Photochemical	Graedel Review	1974	X	X												OH & HO_2		RH	NO_2					
32	Free Radical	Crutzen Review	1974	X										X			OH								
33	Metal Sulfite Catalysis	Freiberg	1975	X	X		X	X	X		X	X						X			X				
34	Nucleation & gas liquid equalib.	Takahashi, et al.	1975	X			X	X	X	X	X														X
35	Plume dilution effects distrib.	Augustine & Boubel	1975					X	X	X															
36	Photochemical	Davis & Klauber	1975	X			X							X			OH & HO_2			NO & NO_2					X

systems on grounds of inordinate difficulty in solid waste disposal), the ability to model quantitatively such trade-offs is of key importance to a scientific assessment methodology centered on mathematical modelling. Model representation of the major unit operations of coal combustion and conversion is thus a crucial link between siting, and air and water quality models. Quantitative specification of the relationships between pollutant emission levels and energy and cost penalties are also a necessary component of credible policy assessments.

Work was thus initiated to develop computer model representations of the unit operations shown on Figure 11, the objective being to capture sufficient detail for accurate analysis of policy issues, but without design level detail (which in any event would be too specific to a particular manufacturer or proprietary process). These models are designed to be linked directly to the siting model (described in Section 6.4) such that point-source emissions can be defined for the types of air quality model discussed in the previous section.

8.4. Current Work (FY 1977): The National Coal Utilization Assessment

In the current year, the RESP will emphasize coal utilization in the Northeast as part of the National Coal Utilization Assessment (NCUA), an assessment being conducted by six National ERDA Laboratories under sponsorship of the Division of Technology Overview, U.S. Energy Research and Development Administration.

The objective of the NCUA is to develop an assessment of the increased utilization of coal in the United States, consisting of a series of regional perspectives (with the BNL effort focused on the Northeast), to be integrated into a national perspective by Argonne National Laboratory. It is unique in its synthesis of a national policy perspective from a series of integrated regional studies, and in its focus on policy assessment, and is concerned primarily with the environmental and policy ramifications of increased coal utilization as based on the current state of knowledge and assessment methodology, rather than with the development of new scientific information.

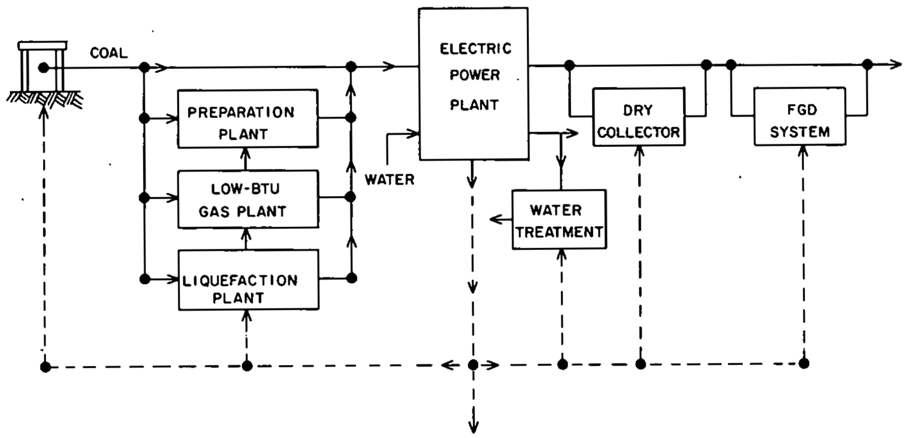

Figure 11. Unit operations models.

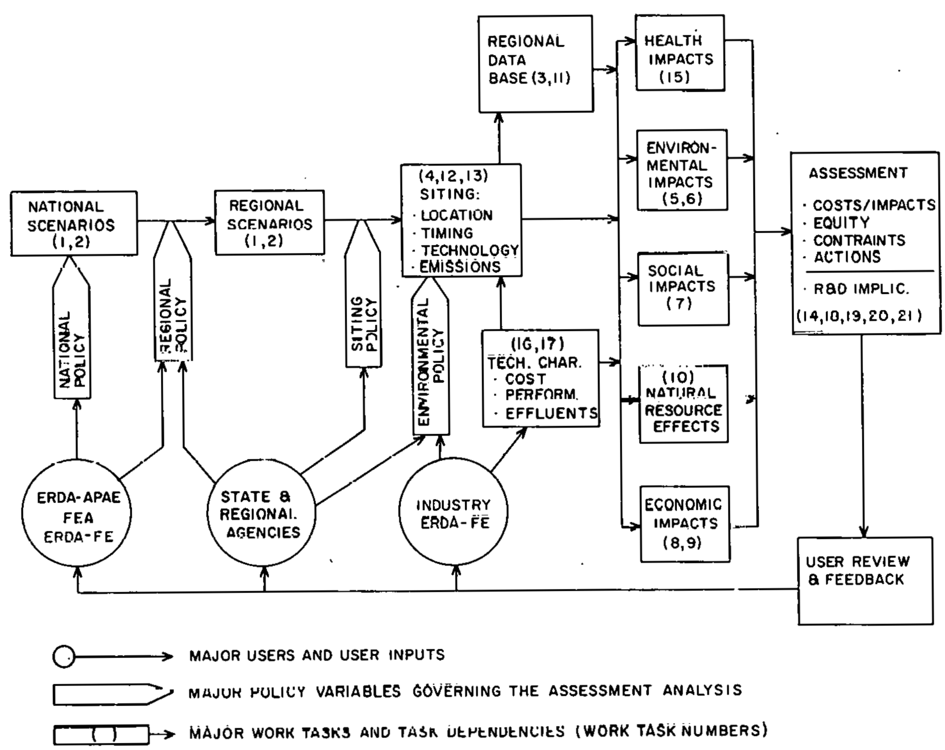

Figure 12. Study approach.

In the Northeast, most of the important issues related to coal utilization are linked to the ability of the region to obtain coal (especially due to its disadvantageous geographic position with respect to coal supply sources, and its ailing transportation system), and the environmental, health and regulatory issues associated with the combustion of coal. The environmental impact issues of coal extraction, limited primarily in the Northeast to Western Pennsylvania, will be treated as a component of the assessment of extraction related issues in the Appalachian Coal Province as a whole, a complex of issues that is a major focus of NCUA Work Program at the Oak Ridge National Laboratory.

The overall NCUA study approach is detailed in the NCUA Program Plan, from which Figure 12 is drawn. A strong committment to user participation and feedback is a central feature of the study: State and Regional Agencies, as well as industry and federal agencies other than ERDA, are seen as participants as well as users. Only in this way will the regional and national assessments, which are destined for use by ERDA as input into its decision-making process, be adequately sensitive to local, state and regional concerns and interests.

Table 10 summarizes the specific work tasks to be initiated in the first 9 months of the study, showing also the relationship of each BNL task to the overall NCUA Program Plan. Although the NCUA is designed as a two year program, the project schedule will provide for a first year interim assessment to fulfil ERDA requirements.

In the first nine months the BNL work program will have two points of emphasis. The first centers on the air quality and health impacts of coal combustion, together with the related problems of siting, and emissions regulation and control (Tasks 4, 5, 6, and 21). The second centers on a spectrum of insitutional and economic barriers to the increased utilization of coal in the Northeast including issues associated with the transportation system (Tasks 18 and 19), and tax incentives, especially at the federal level, (Task 20). The other key issue identified thus far as an important barrier to increased coal utilization in the Northeast concerns

TABLE 10

WORK TASK SUMMARY

BNL WORK TASK	PROGRAM PLAN WORK TASK CATEGORY*
1. Initial Scenario Development	I-A Scenario Development
2. Regional Energy-Economic Analysis	I-A Scenario Development
3. State Level Energy Information System	I-B Geographic Apportionment
4. Base-Line Siting Scenarios	I-C Component Siting
5. Regional Atmospheric Transport and Health Effects of Sulfates	I-D Coal Utilization Impacts (air quality, health effects)
6. Acid Rain Issues	I-D Coal Utilization Impacts (air quality, ecosystem effects)
7. Socio-economic Impact Issues	I-D Coal Utilization Impacts (socio-economic)
8. Employment Ramifications	I-D Coal Utilization Impacts (socio-economic)
9. Case Studies of Socioeconomic Impacts	I-D Coal Utilization Impacts (socio-economic)
10. Water Assessment	I-D Coal Utilization Impacts (water)
11. Northeast Energy Reference Book	I-E Regional Assessment (a. Regional Characterization b. Issue Identification)
12. Siting and Supply Strategy Analysis	I-E Regional Assessment (g. Siting & Supply Strategy)
13. Off-shore Coal Assessment	I-E Regional Assessment (g. Siting & Supply Strategy)
14. Interim Regional Assessment Report	I-E Regional Assessment (a. thru h)
15. Handbook on Health Impacts	II-A Health Effects
16. Process Characterizations	II-C Technology Characterizations
17. Model representation of unit operations	II-C Technology Characterizations
18. Coal Supply and Transportation	III Mitigation Analysis
19. Institutional Problem on Coal Transportation	III Mitigation Analysis
20. Tax Incentives Assessment	III Mitigation Analysis
21. Analysis of Non-deterioration policy and Clean Air Act Ammendments	III Mitigation Analysis

*As defined in the ERDA Program Plan for the NCUA solid waste disposal and its attendent environmental problems, an activity contingent on prior completion of the water resources-water quality inventory (Task 10). Tasks 3 and 11 (The Energy Reference Book and the information system) are designed as adjuncts to BNL's program of user interaction.

Finally, by virtue of special capabilities resident at the BNL National Center for Analysis of Energy Systems, BNL has been assigned certain lead responsibilities in the areas of Scenario Development (Tasks 1 and 2), Technology Characterization(Task 16, 17) and Health Impact Assessment (Task 15). These activities are in support of the CUA as a whole, rather than being limited in focus to the Northeast.

Further details on these work tasks can be found in the BNL "Program Plan for the National Coal Utilization Assessment".December 1976.

Pilot Study for Estimation of Excess Mortality in the Northeastern United States due to Atmospheric Loading of Sulfur from Energy Production: Currently one of the more important activities within the NCUA is a pilot study of sulfate health impacts. The immediate objective is the calculation over one month of the daily SO_2 and SO_4 concentrations in the atmosphere in the northeastern United States using archived source emission and meteorological information. This pilot study is designed to ascertain the relative accuracy of the present assessment models employed to estimate concentrations. For the period in question, July 1975, daily SO_2, SO_4, ozone and particulate air quality data are available on the regional scale, thereby comprising a unique pollution data set until the ERDA MAP3S or EPRI SURE programs get under way. Figure 13 illustrates a typical data set for sulfates as used in this analysis. In addition, dose response relations are being applied to census data to estimate excess mortality expected from SO_2, SO_4 and particulate atmospheric loading on a geographical grid roughly comparable to county resolution.

We believe that a tracking of the pollution patterns in space and time over the thirty-day period in the Northeast would constitute a preliminary endorsement for the procedure used in estimating the pollution

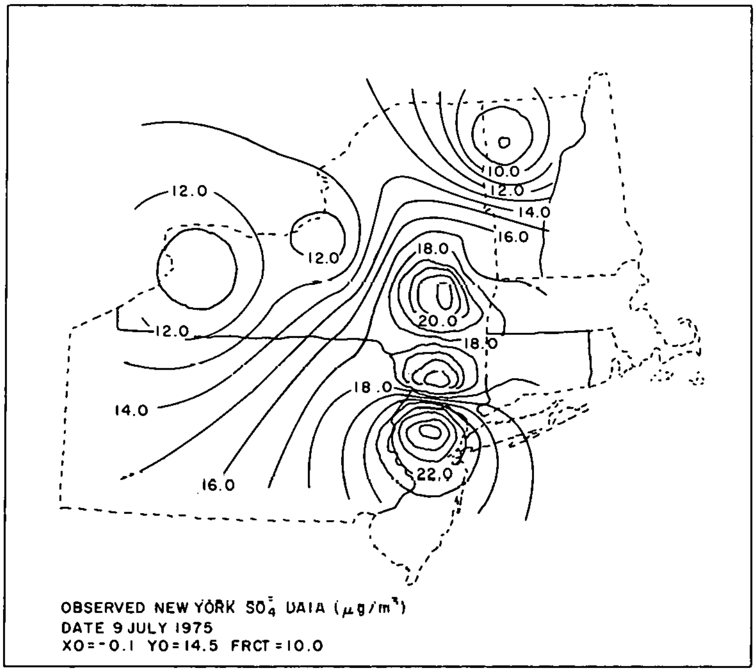

Figure 13. Observed SO_4 data for New York, July 9, 1975.

from energy and other sources since the quickly changing patterns exhibit more degrees of freedom than could be expected to be tracked by an incorrect model. Since sufficient climatological air quality, emission and meteorological data are difficult to process and, in themselves, probably not adequate for full verification of sulfate models on a regional basis, case histories for which data exist are being investigated in more detail first. The reconstruction of climatological pollution patterns by calculation over the past twenty years and projections for the future due to increased production is a longer range goal of this program for which the pilot study is needed to organize and calibrate procedures.

Energy Pollutant Transport and Assessment Modeling for CONAES (Ron Meyers, Ric Cederwall)

This study is being performed for the National Research Council Committee on Nuclear and Alternative Energy Systems (CONAES) of the National Academy of Sciences for ERDA in cooperation with other ongoing BNL programs. Our focus is the calculation of air quality and health impact in the United States of power plant effluents due to incremental increases in nuclear and fossil fuel energy production during the years 1975 to 2010. The cornerstone of the analysis is the regional atmospheric pollution transport model developed previously at BNL in the Regional Studies Program (See previous Annual Report, BNL 50478), and subsequently used in a number of studies reported in the scientific literature.

Notes to Section VIII

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IX. OFFSHORE & RELATED ENERGY DEVELOPMENTS

One of the most immediate and important sets of energy planning issues in the Northeast U.S. revolves around the use of the coastal zone. The coastal region is the most highly valued part of the region for non-energy uses and at the same time potentially the most prone to energy development. Potential development can come in the form of deep water ports, and sites for nuclear power plants as well as the production of offshore oil and gas with associated coastal development.

The BNL program in this area is currently focused on two types of activities: (1) The development of oceanographic and other models that are required to analyze the impacts of activities (oil production, facility siting, etc.) conducted offshore, and (2) the analysis of special policy issues associated with offshore energy development.

9.1 Computer Modelling for Ocean Pollution Assessment (A. Tingle)

A numerical computer model of the N.Y. Bight ocean shelf, whose main features were described in our previous annual report (BNL 50478) continues to be used for assessing hazards to particular coastal regions from offshore petroleum activities. In addition, the model was used at the request of NOAA to simulate the ocean transport of debris that washed ashore and resulted in the closing of Long Island beaches during June 1976. The model can be coupled to other models of marine productivity, and chemical and biological processes, as they become available.

The currents are computed by using a computer model that is widely used by oceanographers when the water column is of constant density. The currents then tend to be of the same speed and direction at different depths. The model results for the month of September 1975 were compared against observations taken by BNL off the south shore of Long Island, current patterns in the N.Y. Bight obtained by the MESA New York Bight project, and various drift card studies. The model responds in a realistic manner when the ocean is non-stratified. The surface level observations were partly simulated when the ocean was stratified, but the model bottom topography and stress will have to be modified for more realism as additional observations become available.

The bottom topography of the area to be modeled must be obtained and the effects of prevailing current patterns should be considered, if known. Then the winds from observations, or from weather forecasts, are needed to drive the model dynamically. The current vectors and free surface elevations for an array of grid points are then computed as a function of time.

The trajectories of oil spills and other floating material are computed by releasing marked particles at selected grid points and advecting them as the vector sum of the currents and a percentage of the wind speed (typically 3%). Material in the water column is advected with the currents. Because the particles are marked, additional facts about the material being studied can be added, such as the effects of aging, or that only some trajectories are meaningful. Therefore the model serves as a useful tool for posing a large variety of questions and for selecting situations and events that merit further analysis with more comprehensive physical reasoning.

Oil Spill Trajectories: The application of the model to the oil spill problem will illustrate the above techniques. The bottom topography of the model ocean shelf is shown in Figure 14, looking up the Hudson canyon from the shelf break toward New York in the upper left. The model depth does not exceed 200 meters and the grid points are spaced at 5.7 kilometers. The complexity of the computed currents is shown in Figure 15. Here the land is on the left and the deep ocean on the lower right, both marked by the letter "C". The length of the vectors is partly proportional to the current speed, the small one meaning 1-5 cm/sec, the middle size 5-15 cm/sec, and the large one greater than 15 cm/sec. If the speed is less than 1 cm/sec, a period is placed at that grid point.

In the study, a hypothetical spill was released each 12 hours from 14 scattered grid points for a six month period (October 1974 to March 1975). The winds were obtained from observations taken at BNL for that period so that the results could be compared with independent drift card releases

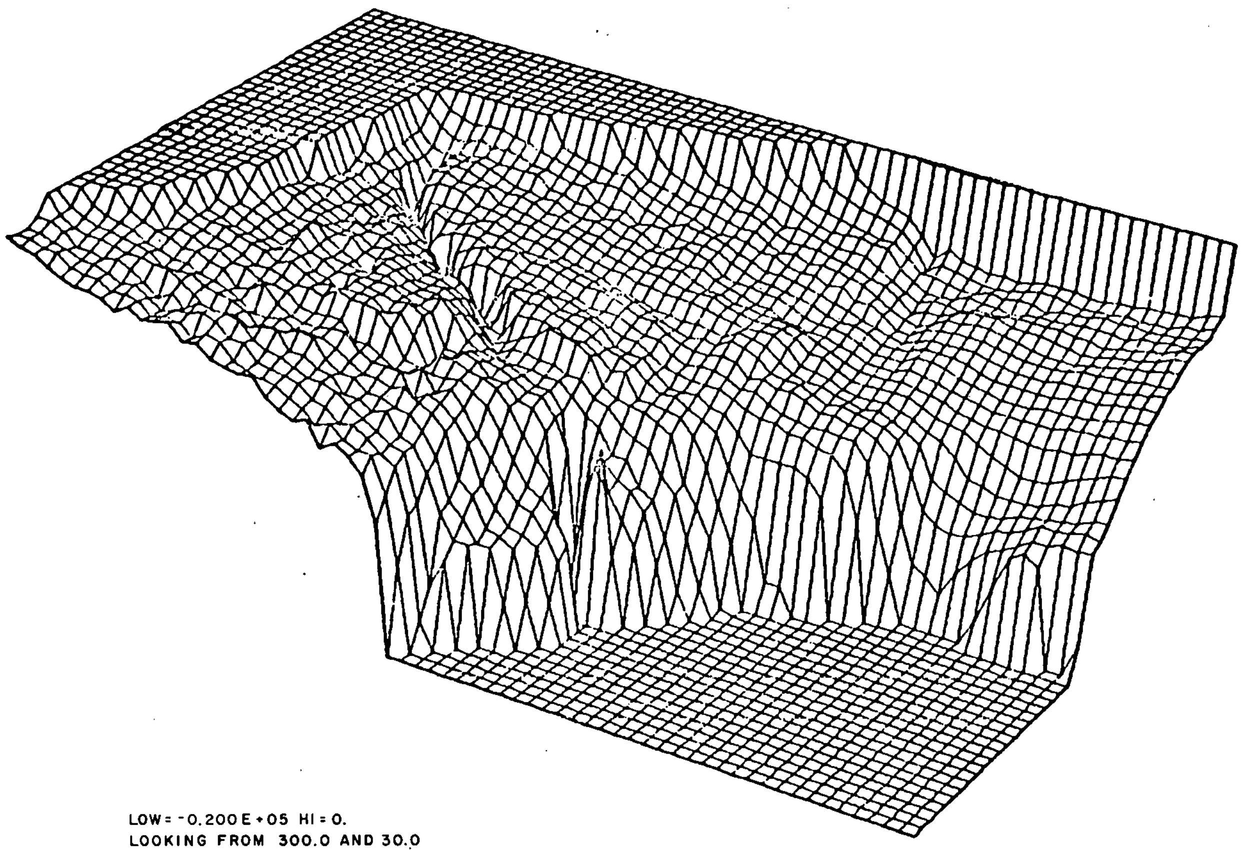

Figure 14. Overview of New York Bight Region.

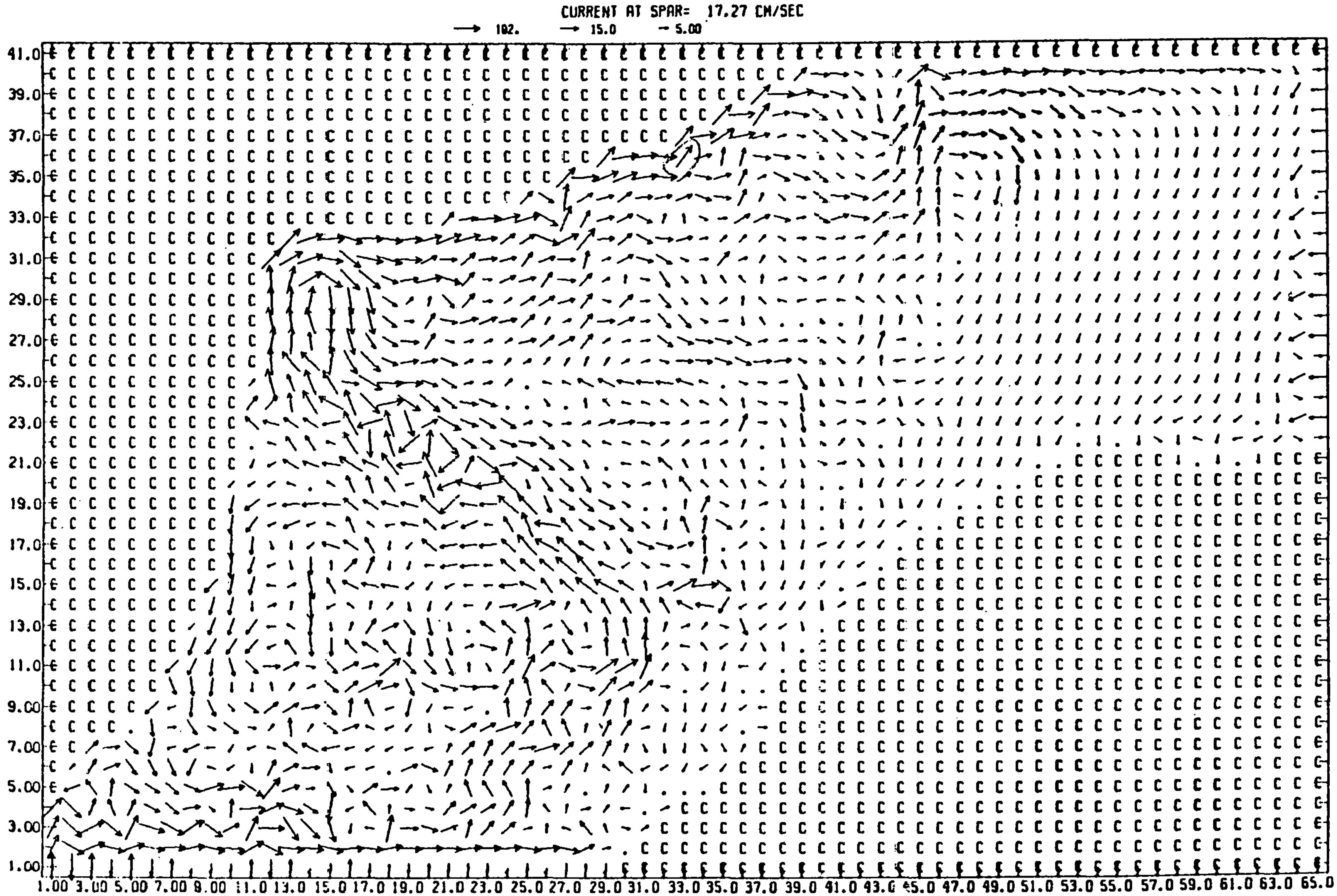

Figure 15. Computed currents showing a complex pattern and a strong clockwise gyre in the New York Bight.

sponsored by the MESA project. The release points are marked by the "X's" in Figure 16. The sample trajectories were released on October 10 and tracked until they hit the shore or moved out to sea. The spill locations are labeled each two days and "ticked" each 12 hours.

The results showed that 96% of the hits occurred within 6 days, spills beyond 15 miles from the shore had a very small chance of hitting the shore, most hits occurred eastward of the release points, and that areas near Fire Island Inlet and Shinnecock Inlet had a higher probability of being hit than other areas. The computer results were in excellent agreement with the drift card observations.

The Pollution Closing of Long Island Beaches

In June 1976 several Long Island beaches were closed because material consisting of raw sewage, garbage, and human artifacts was being washed ashore. This problem had serious implications for the health of the public and the economics of the tourist season. The computer model was used during the event to assess the extent of the problem by simulating trajectories of floating debris from a variety of hypothetical source regions in the New York Bight.

The potential sources consisted of routine ship dumping, routine sewage discharges into the Hudson River, New York pier fires in early June, a sewage tank explosion in Nassau County and associated clean-up operations, and dumping at the sludge dump site.

The observed 10-meter hourly winds taken from the BNL Tiana Beach tower were used to drive the model and compute the surface transport. The historical wind records at BNL were also examined and similar cases of strong, persistent southwesterly winds were found four times in 13 years of data. Therefore, the model was also used to see if there was anything particularly unusual about June 1976, since the beaches were not closed in the other cases.

The most striking feature of the results was the variability of the computed currents throughout the period, considering the relatively steady southwest winds. However, all particles floating in a large area southeast

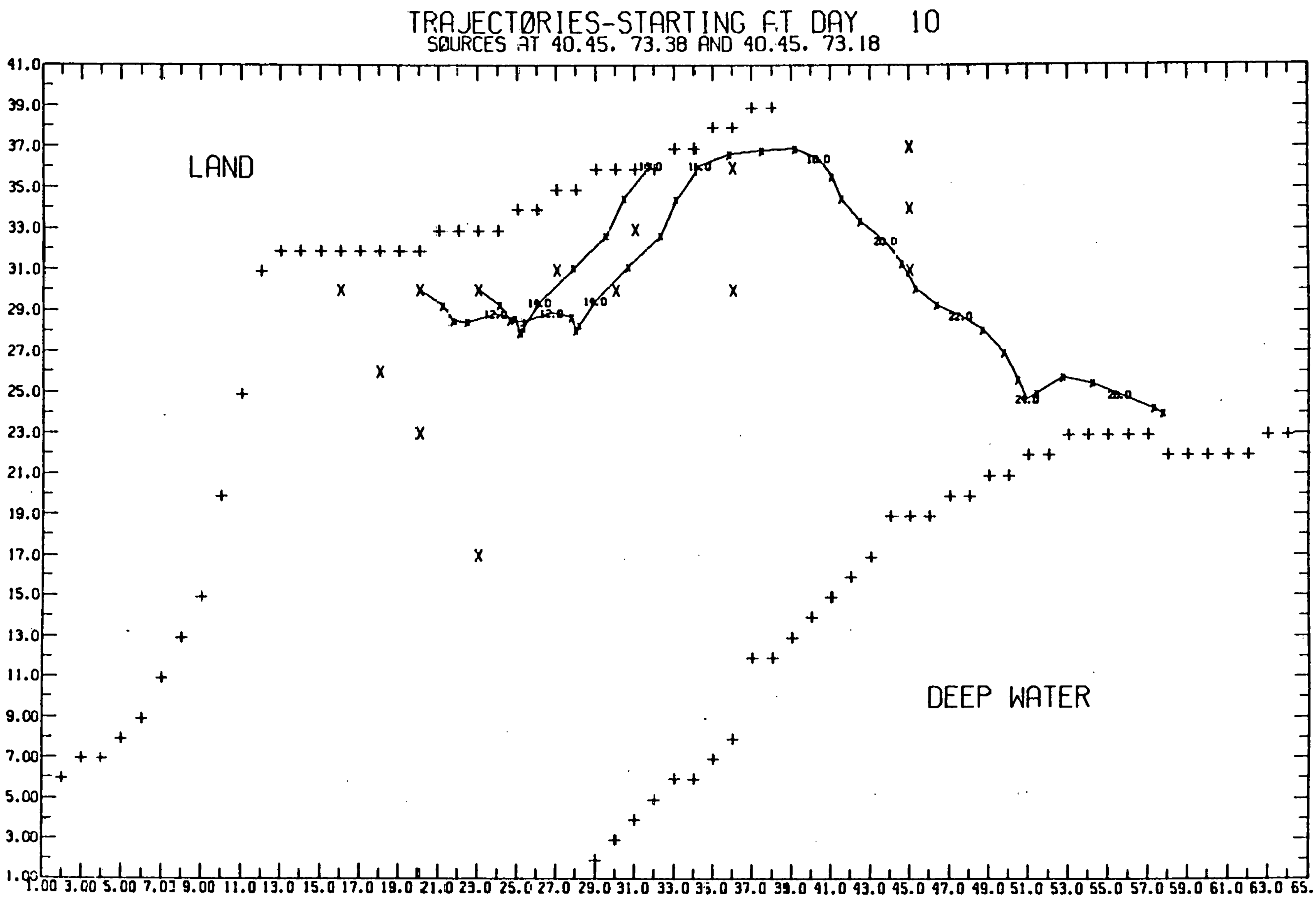

Figure 16. Two simulated spills. One hit the shore in 6 days and the other went out to sea after 17 days.

of New York in early June hit Fire Island in a week or so, which is about the time that the beaches were first closed. This indicates that the pier fires, the tank explosion and sewage from the Hudson could have contributed to the start of the problem. The persistence of the beach fouling could have been caused by material dumped from ships and even released as far south as Atlantic City. The model results simply that the problem should have ended in late June, in accordance with the facts. A summary of the analysis is given in Figure 17, showing the wide range of travel and release times from various sources that could have contributed to the problem.

9.2 Policy Analysis (D. Morell*)

Two specific policy assessments were started in the reporting year, whose results will be forthcoming early in 1978. The first is focused on Oil Refinery siting and its associated off-shore and on-shore impacts, using the Shell Oil Company's proposal for a new refinery in Gloucester County, N.J. as a case study (the refinery was originally proposed for Delaware, but was rejected by the State, and became the proximate cause for passage of Delaware's stringent Coastal Zone Management Act). The second policy analysis will analyze the relationship between OCS development and the tourist industry, using Ocean County New Jersey as a case study. This analysis will attempt to go beyond the usual rhetoric to provide a more accurate data base on the structure and economic importance of the tourist industry in a coastal zone, and to provide a more quantitative assessment of the nature and magnitude of impacts resulting from energy development in the Baltimore Canyon area.

9.3. Current Work (FY 1977): Environmental Assessment of OCS Policies:

Among the many mid-term energy supply programs being implemented by the federal government perhaps the most controversial is the exploration and development of potential Outer Contenental Shelf oil and gas deposits. Many state and regional policy-makers have expressed concern over the possible environmental impacts associated with increased coastal traffic, coastal zone development, oil and gas recovery, and oil and gas transportation from the drilling sites. While the northeastern states have established

*Center for Environmental Studies, Princeton University.

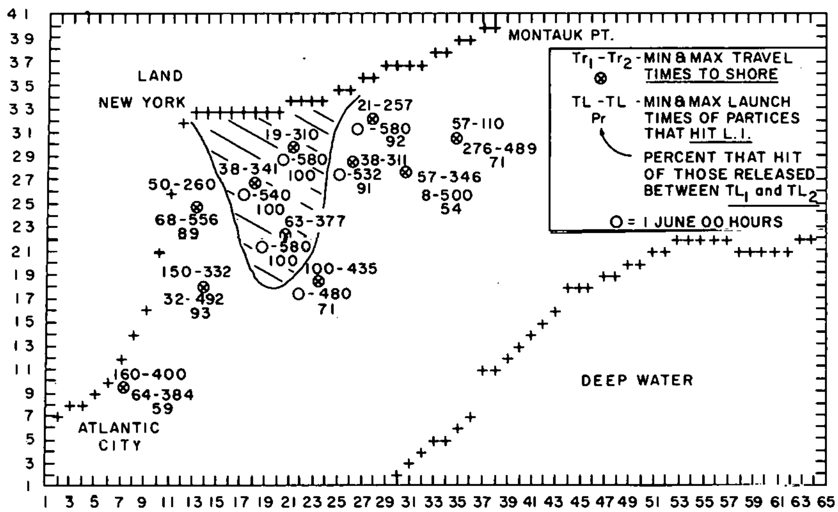

Figure 17. A statistical summary of all trajectories for 11 of the 45 release points. Time is in hours for 00 EST June 1. The code is at the upper right.

programs to assess the onshore impacts of OCS development, they do not, generally, have the funding or manpower necessary for an assessment of the potential environmental impacts of the drilling activity, pipeline transportation and tanker traffic along the coast. Building on the Perspectives Study, the Regional Studies program will conduct an assessment of the Environmental Impacts of various oil import & OCS development options, to consist of the following major study elements:

- --characterization of regional energy supply and demand, to include levels of OCS activity and intensity of petroleum imports.
- --technology characterization, including atmospheric emissions, aquatic discharges, and other recognized or potential forms of pollution associated with OCS development and petroleum importing technologies.
- --an assessment of the "most likely" geographic distribution of drilling rigs, transportation terminals, pipelines, and energy facilities associated with each level of petroleum importing or OCS production.
- --a comparative analysis of the distribution and extent of the potential impacts associated with each level of OCS activity or petroleum importing, using the Oceanographic Pollution Assessment model for spill trajectory evaluations.

Offshore Siting Assessment for Coal Burning Power Plants: Off-shore siting is an intriging option for coal facilities in the Coastal Northeast. This siting alternative, especially in view of the prevailing weather patterns that tend to transport pollutants from west-to-east, may alleviate many of the environmental, land use and socio-political-regulatory problems with siting coal facilities on land. Moreover, it is conceivable that off-shore siting may be economically competitive with on-shore siting, since once-through cooling, and the ability to burn higher-sulfur coal without flue gas desulfurization systems may offset higher construction and transmission costs. Moreover, coal transportation costs may be significantly lowered by direct barging to the site (without an additional water-rail transfer, and using the barges themselves as the storage facility at the off-shore site).

As part of the NCUA (See above, Section 8.4) an exploratory analysis of the suitability of this concept in the Northeast will be prepared, identifying key issues in terms of technical feasibility, economics, regulatory and socio-political implications. An 800 Mw unit will be used for case study analysis, both in the floating mode (similar in concept to the nuclear Atlantic Generating station proposed for coastal New Jersey), and as artificial islands. Previous BNL work in off-shore siting will be used as the starting point for the analysis,* and the assessment will be coordinated with generic studies underway elsewhere (e.g. work currently ongoing at TRW).

*See T. D. Backstrom and M. Baram "Artificial Islands for Cluster Siting off-shore Energy Facilities: An Assessment of the Legal and Regulatory Framework" BNL 50566, Nov. 1976.

APPENDIX: PUBLICATIONS

I. SUMMARY REPORTS

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THE BROOKHAVEN NATIONAL LABORATORY REGIONAL ENERGY STUDIES PROGRAM

The Brookhaven National Laboratory Regional Energy Studies Program is part of a national effort supported by the U.S. Energy Research and Development Administration (ERDA) to create an energy assessment capability which is sensitive to regional conditions, perceptions, and impacts. Within ERDA, this program is supported by the Division of Technology Overview and includes, in addition to a concern for health and environmental impacts of energy systems, analysis of the complex trade-offs between economics, environmental quality, technical considerations, national security, social impacts, and institutional questions. The Brookhaven Program focuses on the Northeast including the New England states, New York, Pennsylvania, New Jersey, Maryland, Delaware, and the District of Columbia. The content of the program is determined through an identification of the major energy planning issues of the region in consultation with state and regional agencies. A major component of the program in 1976 was the Northeast Energy Perspectives Study which examined the implications of alternative energy supply-demand possibilities for the region. In 1977 a major component is the northeast portion of the National Coal Utilization Assessment carried out in collaboration with several other laboratories in other regions of the United States.