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AN INTEGRATED, LONG-TERM ECONOMIC, ENERGY-MARKET AND EMISSIONS POLICY MODEL*

by

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1 INTRODUCTION

In 1980 the U.S. Congress passed legislation creating the National Acid Precipitation Assessment Program (NAPAP), a 10-year research program. NAPAP is a multiagency effort and its organization includes an Interagency Science Committee, an Interagency Policy Committee, and seven task groups. Task Group 1, on Emissions and Controls, is chaired by the U.S. Department of Energy (DOE) and charged with three areas of responsibility:

(1) Provide accurate estimates of emissions of precursors of acid deposition and historic emission trends.

(2) Provide an integrated model set capable of projecting future emissions and costs under a variety of assumptions and policy alternatives.

(3) Assess and help advance emission control technology.

The focus of this paper is on the NAPAP Integrated Model Set (IMS). The IMS must reflect the state-of-science in modeling and must be documented and compared with other approaches in the literature in a NAPAP State-of-Science report. The IMS has been developed for use in the NAPAP assessment planned for 1990 [NAPAP, 1989]. This assessment must be credible and based on a consistent set of assumptions. This consistency is derived from an integrated approach, in which a common set of assumptions is used to drive the components of the IMS.

The components of the IMS include economic and energy scenario driver modules, sectoral energy use and emissions models, feedback loops, and integration connections. Each of the model components and the economic and energy driver modules and the integration approach have undergone third party review. For example, the driver modules and integration approach were reviewed by National Economic Research Associates (Curkendall, 1988), and the transportation sector module was reviewed by Cambridge Systematics, Inc (CSI, 1988).

Section 2 of the paper begins with a review of approaches which have been used for integrated long-term modeling. Section 3 is an overview of the configuration of the NAPAP IMS, including a description of this application and how it is planned to be run for the 1990 NAPAP Assessment. Sections 4-7 provide a description of the four steps in the IMS: (1) scenario preprocessors, (2) annual recursive state loop, (3) emissions postprocessor models, and (4) aggregation, feedback and report writing. The computer implementation of this system is summarized in Section 8. Some preliminary test results from the IMS are presented in Sec. 9. A brief summary is provided in Section 10. It is hoped that after NAPAP is finished with its 1990 assessment, the tools that it has developed will be useful for other assessment and policy studies.

2 A REVIEW OF APPROACHES USED IN INTEGRATED NATIONAL LONG-TERM MODELING

Three approaches have been used to model national energy markets and emissions: General equilibrium models, disequilibrium models, and programming models. This section will describe these approaches and provide examples. It is not intended as an exhaustive list or review of energy and emissions models.

General equilibrium models consist of a set of integrated submodels describing various sectors of the economy, such as the household sector, business sector, and government sector. These sector models interact by exchanging data until all sectors have attained equilibrium. Two examples of general equilibrium models are the PC-AEO model and the TESOM/9DGEM model.

The PC-AEO modeling system of DOE's Energy Information Administration (EIA) is a series of linked spreadsheets used to forecast national energy trends for various sectors and fuels in the United States. The system includes a macroeconomic model and models describing the residential, commercial, industrial, transportation, and electric utility sectors and the fuels petroleum coal, oil, and natural gas. Each spreadsheet model can be operated independently or the models can be integrated by exchanging price and quantity data repeatedly among the models until energy balance and economic equilibrium are attained.

The TESOM/9DGEM model is a general equilibrium model of the U.S. economy with an explicit treatment of the energy sector. The model consists of a set of submodels describing the household sector, producer sector, investments, exports, and government expenditures. The producer submodels determine input purchases, which minimize average production costs for the prevailing set of input prices, while the household model determines the demand for goods and services and the supply of labor based on a model of consumer utility maximization. Private investment is determined by capital market conditions that reflect private domestic saving and government and foreign deficits. Government expenditures and exports are determined exogenously. The submodels are solved repeatedly until equilibrium is reached in input and output markets and until consumers and producers have optimized their behavior subject to their financial constraints.

The FOSSIL2 modeling system is a dynamic disequilibrium model of the U.S. energy system. The model is based on a number of exogenous decision rules that determine the flow of resources, investments, and energy-consuming goods. The model uses difference and integral equations to describe the dynamic behavior of four major energy consumption sectors and four major energy-production sectors.

Two examples of programming models are the PILOT energy modeling system and the Market Allocation Model (MARKAL). The PILOT system is a time-phased (dynamic) linear programming model that consists of several submodels. These submodels are input/output models that describe consumer behavior and production in seven nonenergy and five energy sectors. The model optimizes over planning periods for up to 100 years in five-year increments by maximizing a linear objective function. This objective function is usually the present value of personal consumption over the planning period. MARKAL is a multiperiod, linear programming energy supply model. The model contains a detailed description of existing and emerging energy supply technologies. It optimizes a set of preprogrammed objective functions subject to technological constraints and a set of exogenously specified demands. The model is most useful as a technological assessment tool and for analyzing tradeoffs such as emission levels and cleanup costs.

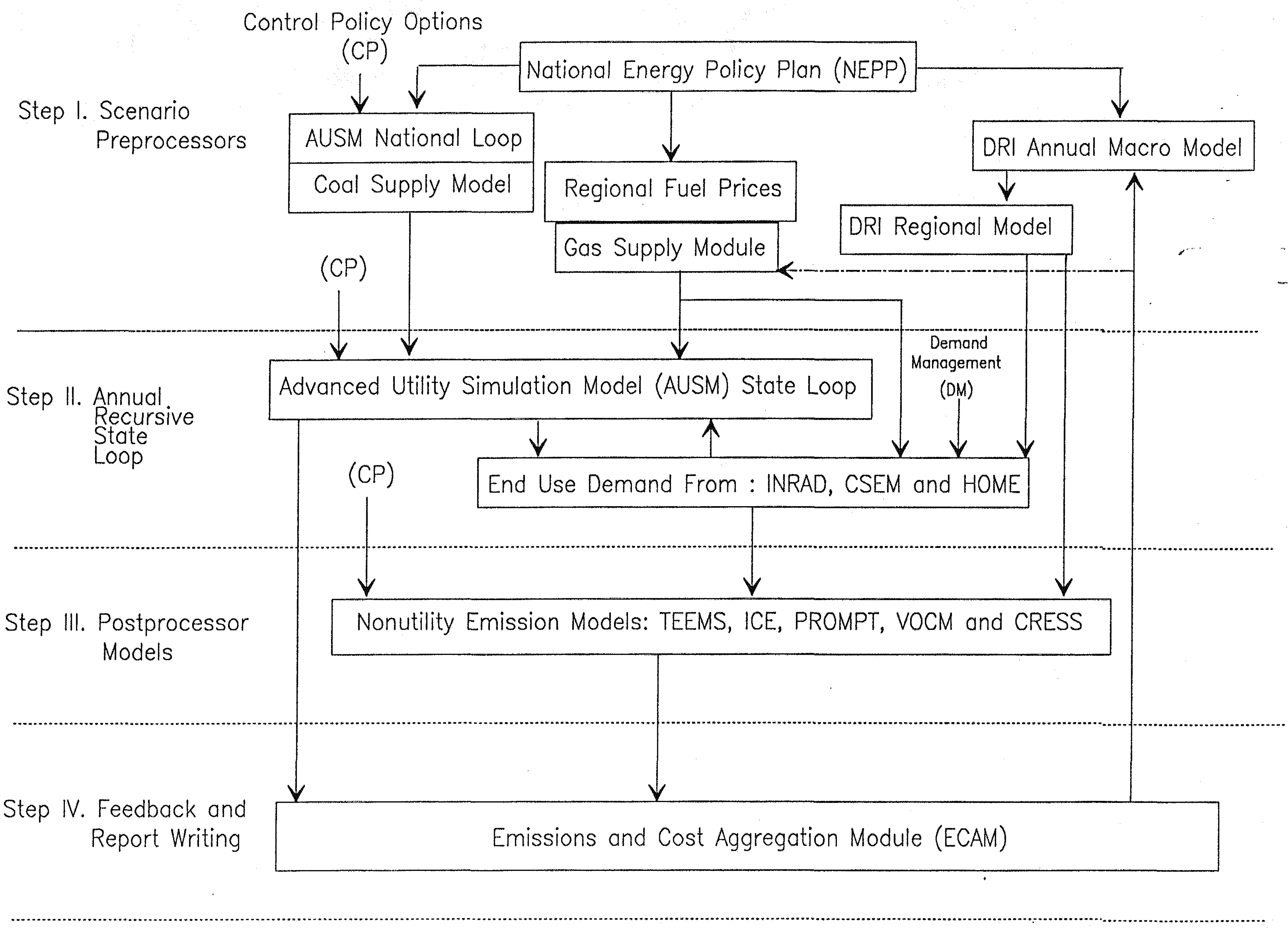
3 OVERVIEW OF THE INTEGRATED MODEL SET

3.1 SUMMARY DESCRIPTION

Figure 3.1 presents a simplified view of the structure of the Integrated Model Set. As the Figure indicates, a model run consists of four steps: Step I is a set of scenario preprocessors, Step II is the annual recursive state loop, Step III is the postprocessor sector emission models, and Step IV is aggregation, feedback and report writing.

A model run begins in *Step I* by providing data on a target GNP growth path, exogeneous energy prices and other variables from DOE's National Energy Policy Plan (NEPP). Emission constraints, if applicable, are also specified for an emissions control policy scenario. This GNP and some energy information from NEPP are used in the Data Resources, Inc., (DRI) annual macroeconomic model to provide a consistent macroeconomic simulation. The DRI macro model forecasts industrial output by sector, housing starts, interest rates and other variables used in the IMS. The macroeconomic simulation is disaggregated in the DRI regional model to determine the regional activity data required by the sectoral energy demand modules and emissions modules. (Bando, et al. 1988)

Overview of the Integrated Model Set



The Advanced Utility Simulation Model (AUSM) national loop creates a preliminary plan for the electric utility system. The national loop calculates a capacity expansion plan for each state (new units by technology type and fuel type), interstate transfers of electricity, and state emission caps. The National Loop's Coal Supply Model (CSM) determines mine mouth prices and the price of the least-delivered-cost coal to each state by sulfur content.

The gas supply model determines a wellhead price of natural gas, given gas demand. Final user gas prices are constructed from wellhead prices by adding transmission and distribution costs to each region. The exogeneous oil prices are also regionalized based on extrapolation of historic patterns.

In *Step II* this information is used by the AUSM state loop to annually model the electric utility industry in each state by determining utility fuel use, electricity output, electric rates, and utility emissions. Electric rates and activity data for each year are passed to the Industrial Regionalization and Disaggregation Model (INRAD), the Commercial Sector Energy Model (CSEM), and the Household Model of Energy (HOME) to determine the demand for electricity and fuels by these sectors. The annual electricity demand data is sent to the AUSM state loop to form the annual recursive loop. Electric rates are calculated by AUSM using a revenue requirements approach.

When Step II of a simulation has been completed for all states, the energy demands from Step II and other activity and price data from Step I are sent to the postprocessor models in *Step III* to calculate nonutility emissions. The Transportation Energy and Emissions Modeling System (TEEMS) is used to determine energy use and emissions from the transportation sector. The Industrial Combustion Emissions (ICE) Model is used to determine fuel choice and emissions from industrial boilers. The Process Model Projection Technique (PROMPT) accounts for emissions from process energy use. The Volatile Organic Compounds Model (VOCM) calculates industrial emissions of nonmethane hydrocarbons. Commercial and residential emissions are calculated by the Commercial and Residential Emissions Simulation System (CRESS).

The sectoral data from Steps II and III are aggregated and summarized by the Emissions and Cost Aggregation Module (ECAM) in *Step IV*. In this step, reports on activity levels, emissions, costs, energy and other resource use are prepared. This information can be returned to the preprocessor models in Step I to provide recursions if necessary to attain a consistent equilibrium.

3.2 NEPP AND THE NAPAP ANALYSIS REFERENCE CASE

Energy price and economic activity forecasts from NEPP-7 provide many of the required scenario inputs for the NAPAP Analysis Reference Case (ARC). Sources of the input assumptions for the ARC are provided in Table 3.1.

The provision of supplemental electricity supply driver data at the state level is described in Hanson, et al. (1988b) for use in AUSM testing. Many of the ARC electric utility supply factors are determined by a joint DOE/EPA agreement.

Proposed sensitivity cases address alternative economic growth rates, power plant retirement ages, nuclear growth, penetration of clean coal technologies, vehicle miles traveled (VMT), world oil prices, and domestic gas resources.

Proposed emission control policies include various ways to reduce emissions. These ways may be more or less efficient and may have other advantages or disadvantages. (1) fuel switching vs. forced scrubbing, (2) adoption of clean coal technologies, (3) alternatives as to which sources/sectors are controlled, (4) mandated retirements in noncomplying units, (5) emission taxes or tradeable permits, (6) alternative financing, (7) strategies relying on increased natural gas use either by co-firing or by seasonal fuel switching, (8) policies implemented in two or more phases, and (9) scenarios that give different weights to reductions in sulfur dioxide, nitrogen oxides volatile organic compounds (SO_2, NO_x and VOCs).

The definition of which sources/sectors to be controlled involves many options in itself. Controls could be considered affecting a wide range of sources: utility, transportation, industrial boilers, industrial processes, solvent use, and commercial fuel use. An advantage of the economic incentive approaches such as an emissions tax is that this approach may be cost effective over a wide range of sources. Controls can also be targetted to those sources deemed to be causing the greatest damage. [Streets, 1984].

It is intended that the IMS be capable of simulating many of the policies listed above. Some of these policies such as intrastate or interstate emission trading will require some postprocessing of model runs in order to calculate efficient, least-cost trades among emission sources. (e.g., see Streets, 1983).

TABLE 3.1 Sources of Input Assumptions for NAPAP Analysis Reference Case (tentative)

Category	Source
Gross National Product and Demographics	
GNP	NEPP-7 GNP path until 2010 GNP extension until 2030 provided by Chris Caton, DRI as embodied in our 2030 version of the DRI Annual macro model.
Population growth and national demographics	U.S. Bureau of the Census middle population growth series as used by NEPP and DRI
Energy Prices and Demands	
World Oil Price	NEPP-7 and long-term extension
Average delivered U.S. oil product prices by sector (extended to 2030 by regression analysis with world oil price as independent variable)	NEPP-7
Nuclear fuel prices	DOE/EIA
Fuel and electricity demand forecasts by sector	Calibrated to NEPP-7 for Analysis Reference Case
Nonfossil electricity supply	
Net electricity imports	NEPP-7 and NERC reports
Industrial cogenerated electricity	FOSSIL2 model
Nuclear capacity and generation	NEPP-7 and EIA
Electricity generation from renewables	NEPP-7, DRI regional shares
Air Pollution Regulations	
NSPS, proposed ozone standards	EPA
Electric Utility Factors:	
Repowering, life extension, retirement, performance characteristics, minimum capacity factors, clean coal technologies, IPPs	Joint DOE/EPA agreement

4 SCENARIO PREPROCESSORS

The first step involves defining the scenarios. Forecasts of key macroeconomic and energy variables are provided from the NEPP simulations. Corresponding economic and demographic variables as forecasted from the DRI macro and regional models. The AUSM National Loop is a linear program which is run as part of Step I to provide an overall plan for the electric utility sector. Key energy prices are also calculated in Step I for: the coal market and the gas market.

4.1 DRI MACROECONOMIC MODEL

The DRI annual macroeconomic model of the U.S. economy is being used to simulate the details of the economic scenario. Being an annual model, it is appropriately suited for the long-term projections (up to the year 2030) that are required by NAPAP. It also provides sufficient industry-specific detail to conform to the input requirements of the remaining components of the integrated model set.

The NEPP specifies information on the growth in gross national product (GNP), world oil prices, and other items related to the energy sector of the economy that are used as inputs to the DRI macroeconomic model. The macroeconomic model is then used to generate a set of macroeconomic and industrial forecasts that are consistent with economic growth provided by the NEPP forecast. The main variable that DRI uses to adjust their GNP forecast is the outlook for the labor force participation rate. The money supply is also adjusted in the macro simulation to hold the nominal short term interest rate constant.

Since the other modules of the integrated model set require regional- and industry-specific drivers, the output from the DRI macroeconomic model is fed into the DRI regional model, which will be discussed in the following section.

4.2 DRI REGIONAL FORECAST

The DRI Regional Information Service (RIS) model provides economic forecasts and historical statistics for 20 industries in nine regions and in 50 states and the District of Columbia. More than a decade of historical data and up to 25 years of consistent forecast data are available. For the integrated model set, time series data for several regional variables were used.

DRI/RIS provided an output file from its January 1989 simulation containing the historic and projected values of the variables in its multisector regional econometric model.

The regional variables from the January 1989 regional simulation have to be scaled to the forecasts from the DRI annual macroeconomic model. The regional data contains forecasts of two types of variables: quantity variables and index number variables. The scaling algorithm for the regional projections of the index number variables required adding the difference between the growth rates from the current macro model run and the January 1989 run of the DRI macro model to the growth rate of the corresponding variable from the regional file. For quantity variables, the regional variables were scaled to match totals provided by the DRI macro model run. Finally, the scaled variables were extended to 2030 using the growth rates obtained from the macro model. Figure 4.1 shows a representation of this scaling methodology.

4.3 AUSM NATIONAL LOOP

The AUSM national loop is an linear-programming-based simulation model that develops a general utility strategic operating plan that is used by the AUSM state loop. The information passed to the state loop consists of projected capacity additions, interstate power transfers, and future coal prices.

The national loop is composed of two basic modules: the multiperiod, multistate (MPMS) programming module, and the national coal supply module (NCSM). A general flow diagram of the national loop showing its relationship to the state module is given in Figure 4.2. The MPMS module is a large linear program that performs a least-cost optimization of electricity production subject to emission and demand constraints. The optimization is carried out on a regional basis over multiple states, time periods, and technologies. In the base case, there are 13 regions, 12 time periods, and 20 technology categories. No parameters are passed between regions. Thus, a single MPMS execution would provide information on capacity planning and interstate power transfers for over the complete modeling time horizon for all states within the specified region. Each region is solved in turn as a separate problem formulation. After all regions have been executed, coal usage information from all the regions is aggregated to provide the input to the NCSM.

The NCSM consists of a large coal-supply model and an equilibrium testing model. The coal-supply model estimates coal prices on a national basis over a 1980 to 2070 time frame in 10-year increments. Prices are given for 35 supply regions, 48 demand regions, 11 coal sulfur categories, and 3 coal heating values. The coal model is executed three times, once for each coal heating value (bituminous, subbituminous, and

FIGURE 4.1 **SCALING METHODOLOGY FOR REGIONAL VARIABLES**

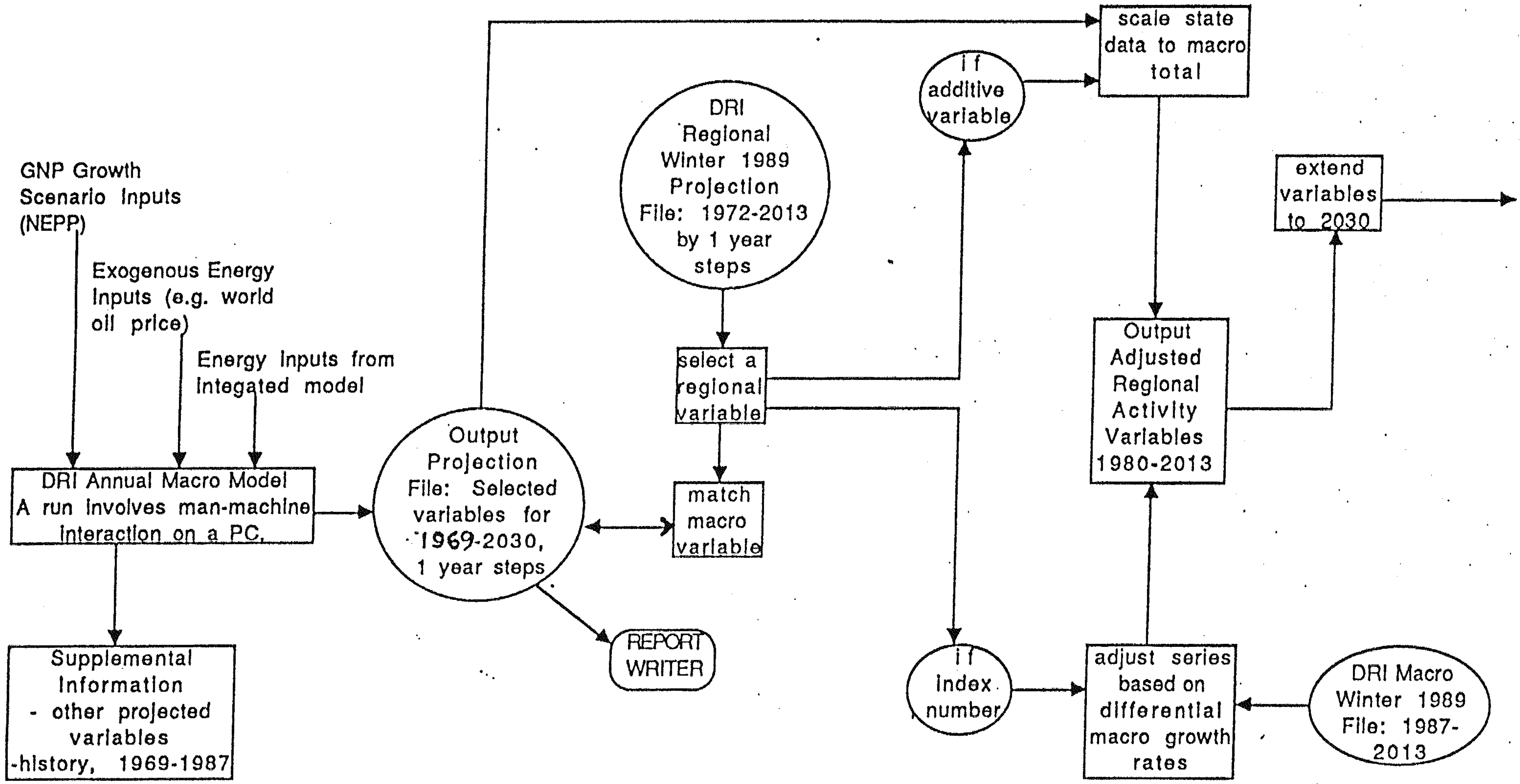


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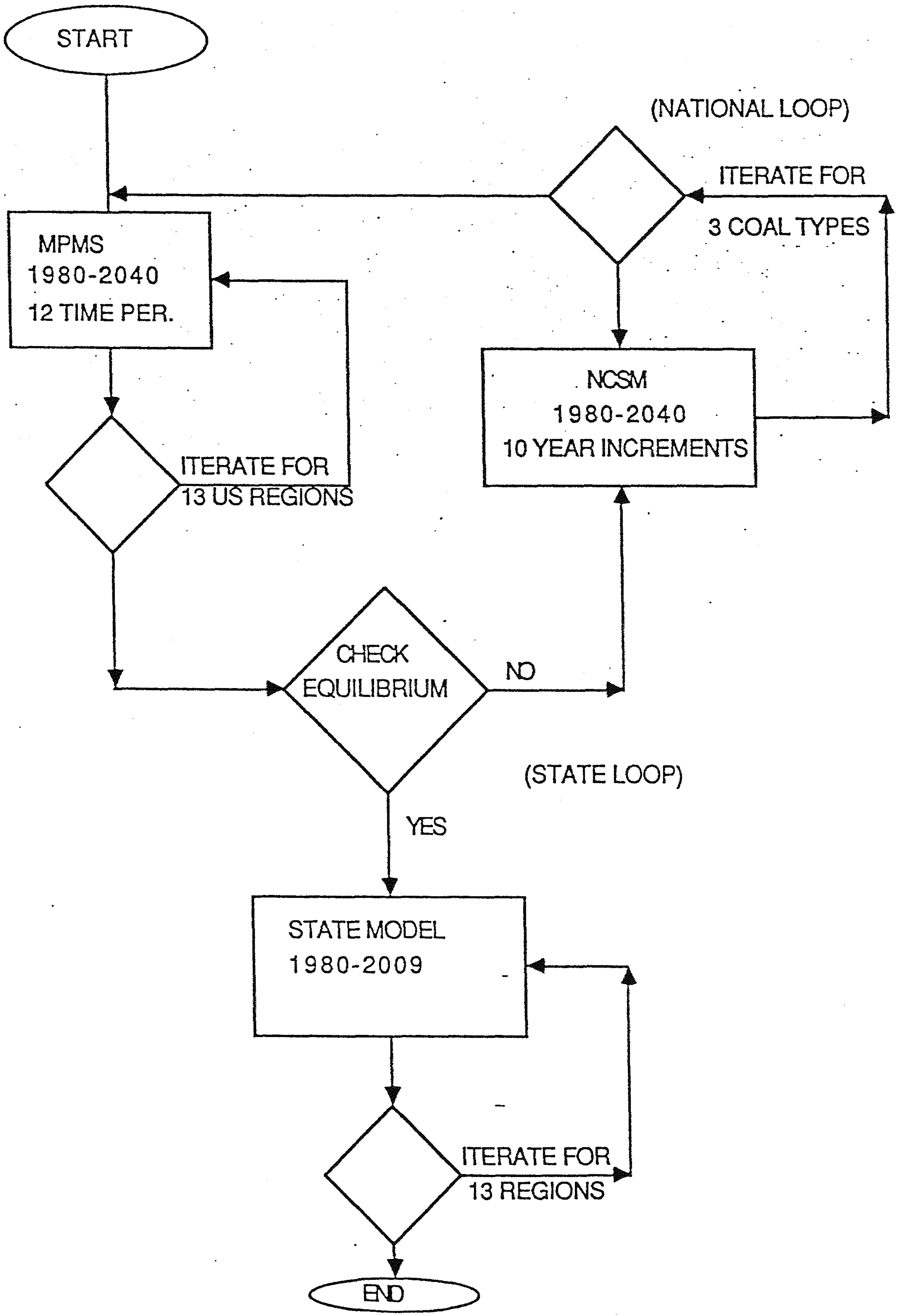
FIGURE 4.2 GENERAL AUSM MODEL STRUCTURE



lignite). An equilibrium model compares the coal demand before and after an MPMS execution; if equilibrium conditions are not met, the coal file is updated to reflect the new demand, and another execution of MPMS takes place. At equilibrium, the resulting coal file becomes the input to the AUSM state loop. The formulation of the NCSM is discussed in more detail in the proceeding section.

4.4 NATIONAL COAL SUPPLY MODEL

The NCSM is run before the detailed AUSM state model simulation. The coal supply module simulates costs of coal production, washing, and transportation and computes delivered least-cost coal as a function of time.

The existence of both near-term econometric and long-term model mine projections allows the AUSM to deal realistically with near-term conditions as well as factors that determine coal prices over the long term. The AUSM capability for short-term coal-supply projection is based on an extensive, detailed data base of information on current coal production and prices and current coal movements. This short-term capability is linked to the standard long-term mine-costing approach so that the overall coal supply module more accurately reflects "inertia" built into the current coal supply and transportation system. The mine-costing algorithms used in the long-term show the effects of escalation of major components (e.g., wages) as well as the effects of cost increases due to severance taxes or other policies.

A major improvement over existing coal supply models is the incorporation of a detailed coal-cleaning model into the AUSM coal supply module. The general objective of coal-cleaning processes is to improve the value of the coal produced by reducing the presence of impurities such as ash, sulfur, and moisture. The reductions are obtainable only at a cost, comprising both the cost of constructing and operating a processing plant and the cost of combustible material that is discarded with the refuse from the preparation process.

The final component in the coal supply module is a set of coal-transportation costs linking each of the supply regions to the 48 demand regions. These origin-destination costs are computed for rail-water and rail-only routings using the U.S. Department of Agriculture's Transportation Analysis System, probably the most detailed representation of transportation networks available. Effects of changes in the system (e.g., escalation of various cost components) on future coal movements and prices can be analyzed

4.5 THE GAS SUPPLY MODULE

The purpose of the gas supply module is to integrate the U.S. domestic natural gas market into the NAPAP Integrated Model Set. This module will determine an endogenous wellhead price for natural gas.

The gas supply module is an adaptation of EIA's Oil and Gas Spreadsheet (OGS) model, which is a submodel of the PC-AEO spreadsheet model used to prepare the *Annual Energy Outlook 1989 with Projections to 2000.* The OGS model is a supply and demand model for natural gas that reads in world oil prices and natural-gas demands from other spreadsheets in the PC-AEO system. Then the model calculates domestic crude-oil and natural-gas production, imports, and the equilibrium wellhead price of natural gas.

The spreadsheet model has been integrated into our system by recoding it into Fortran 77 and inputing natural-gas demand from the other modules as a substitute for the OGS demand functions. Thus in the integrated system, natural-gas demand will be the sum of electric-utility demand from AUSM, industrial demand from our industrial sector models, commercial demand from CSEM, residential demand from HOME, and gas-industry demand from within the model.

The supply of natural gas in the gas-supply module is calculated using the same three-step process and the same econometric functions as those used in the OGS. First, the number of new exploratory gas and oil wells drilled is estimated as function of the world oil price and as a function of an initial assumed gas price. Second, the level of oil and gas reserves is revised based on the proportion of successful oil and gas wells. Third, domestic gas production is calculated as the sum of gas produced from base reserves, new reserves, reserve revisions, and gas associated with oil production. Total gas supply is determined by adding net imports and net withdrawals from storage.

To determine the equilibrium price, the quantity of gas supplied is compared with the quantity of gas demanded. If the quantities are within a tolerable range of 1%, the price remains at the initial assumed price. If the quantities are outside the tolerable range, the price is changed using a sequential interval bisection technique until the tolerable range is reached.

The wellhead price of natural gas determined within the gas supply module will be used in the price module to determine natural-gas prices for each state and for each final-user class by adding transmission and distribution costs forecast by the Gas Research Institute (Holtberg, 1988).

4.6 OTHER FUEL PRICES

Prices for fuels other than coal or natural gas are determined exogeneously. Historical state prices of all fuels used in the residential, commercial, industrial, transportation, and utility sectors were obtained from EIA's *State Energy Price and Expenditure Report 1986* (SEPER). Historical prices for some electric utility fuels for 1987 were obtained from EIA's *Cost and Quality of Fuels for Electric Utility Plants 1987*. Projected national average sector prices for petroleum prices were obtained from the Office of Technology Policies' *National Energy Policy Plan Projections Draft 2 of January 9, 1989* (preliminary NEPP-7). Projected national average nuclear fuel costs were obtained from an input to EIA's *Annual Energy Outlook for 1989*.

These projected national average sector prices were converted into projected state sector prices using Eq. 1:

$$P_{i,j,s} = P_{i,j} + \mu_{i,j,s} \times W \quad (1)$$

where:

$P_{i,j,s}$ = projected state price for fuel i, sector j, and state s

$P_{i,j}$ = projected national price for fuel i in sector j

$\mu_{i,j,s}$ = arithmetic mean difference between the state and national price for fuel i, sector j, and state s between 1980 and 1986

W = weighting factor

The weighting factor is 1.0 in 1987 and declines to 0.7 in 2010, thus assuming a regression of these state prices toward the national mean.

5 ANNUAL RECURSIVE STATE MODEL

The annual recursive state model, described in this section, is based on the AUSM state model and forms the core of the IMS.

As diagrammed in Fig. 5.1, the price and activity data from the preprocessors in Step 1 are provided to the annual recursive loop in Step 2. Step 2 begins by initializing the national data by reading national files on global scenario parameters, demand data, planning data, finance data, and fuel data. Then the AUSM state loop begins; it runs sequentially for each of the contiguous 48 states with annual recursion until the end of the selected period.

5.1 AUSM STATE MODEL ANNUAL RECURSION

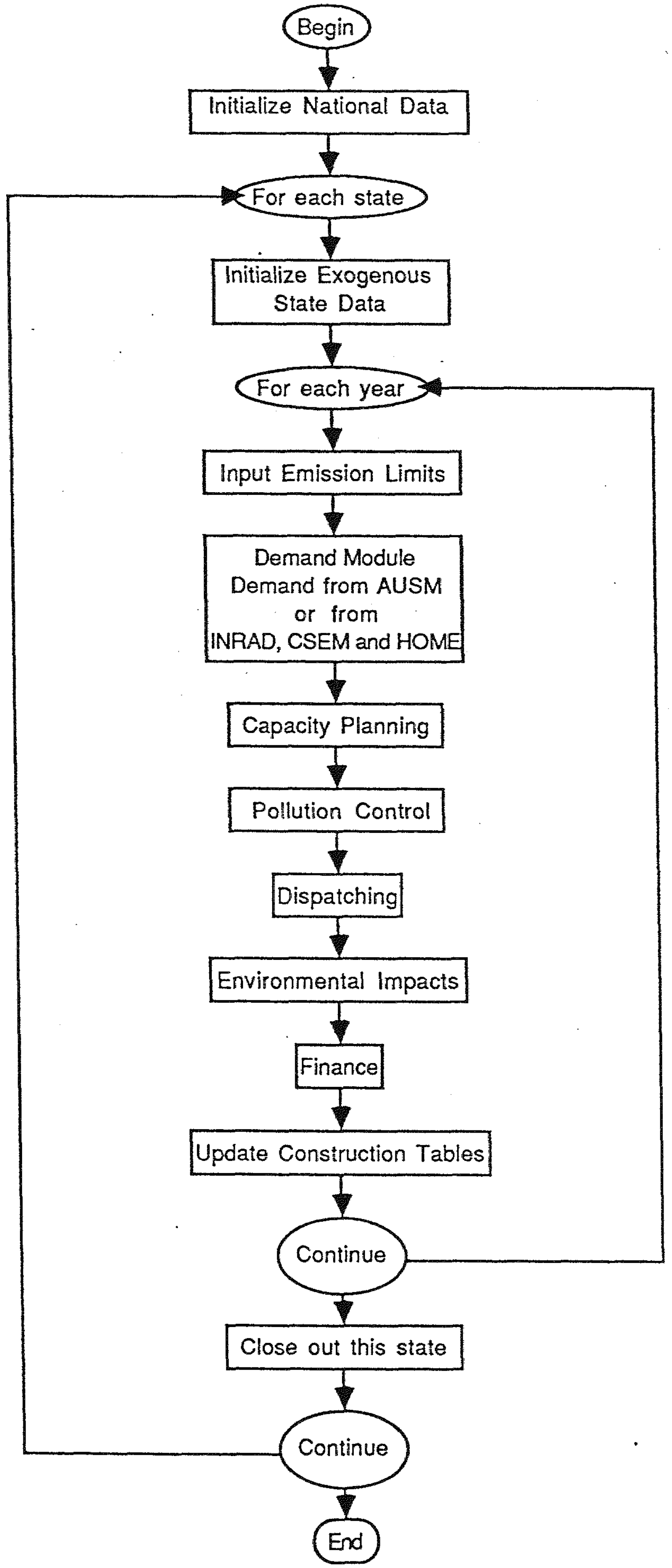
The first step within the AUSM state loop is to initialize the state data. This step includes reading state files on fuel cost, fuel characteristics, projected demand, planning data, and scenario parameters including emission limits.

The next step is to determine energy demand. The demand module begins by determining rate schedules for electricity. These rate schedules are based on historical data in the first year and are updated using information from the finance module in subsequent years. The AUSM demand module allows the user to choose among three methods of determining demand; endogenously using a system of linear logit demand functions, exogenously, or exogenously with annual recursion. The last option calculates price induced changes about an exogenous baseline. A fourth option is added to AUSM by Argonne to complete the IMS. This option specifies the historical demand over the period 1980-1986 exogenously and calculated demand endogenously thereafter based on the energy driver for the NAPAP sector models. These energy drivers are INRAD, CSEM and HOME for the industrial, commercial and residential sectors, respectively. These models provide not only electricity demand to AUSM but also fossil fuel demand to the sectoral emissions modules ICE, PROMPT and CRESS (to be discussed in Sec. 6). Hence overall consistency in the energy forecast is maintained for the purpose of computing emissions.

Electricity demand goes to the capacity planning module to determine a schedule for the construction of electric-utility power plants.

Then the pollution-control module determines the optimal pollution-control strategies at existing plants and those under construction. In addition, this module supervises the construction of pollution-control equipment at existing plants, assigns capacity penalties and compliance costs to these plants, and upgrades their fuel and pollution-control data.

FIGURE 5.1 ANNUAL RECURSIVE LOOP-Based on AUSM State Model



The dispatching module allocates the demand for electric energy among the generating plants available to meet the demand. This module is usually used to find the least-cost allocation of generation that meets emissions limits. The module can be used, however, to determine the allocation that minimizes emissions of a particular pollutant while complying with limits on other emissions and total cost. Then, the environmental impacts module calculates the emissions from fossil-fuel plants and the variable cost of pollution control in each year of the simulation.

The finance module has two main functions. First it calculates the electric-utility revenue requirements based on the cost of existing plants plus the cost associated with new capacity or emission controls. These revenue requirements are used in the demand module to determine electric rates. In addition, the finance module prepares reports on representative state-level utility financial statements.

At the end of the forecast period, the state file is closed out. Summary statistics are printed, and the program loops to the next state until all 48 state runs are completed.

5.2 COMMERCIAL AND RESIDENTIAL SECTOR ENERGY DEMAND

The objective of modeling the commercial and residential sector demands is to develop a module capable of preparing energy-use projections by major fuel types for the two sectors on a state-by-state basis. The models should be capable of simulating alternative baseline scenarios and policy analyses. The models selected to represent these sectors are two EIA models: CSEM and HOME. These models need to be consistent with the AUSM state loop and with the input requirements of the emissions module that is described in Sec. 6.5. As part of the IMS, these models provide sectoral electricity demand projections for the AUSM state loop and fossil-energy use projections for the CRESS Emissions module. Revisions had to be made to these models (1) to increase the time horizon to 2030 as required by the IMS, (2) convert them to operate for individual states rather than at the regional level, and (3) to enhance their fuel substitution specification. To project fuel consumption for each end-use, the models follow three basic steps:

(1) update the basic sectoral activity variable, floorspace in the commercial sector, and housing stock in the residential sector;

(2) adjust the share-of-activity variable using each fuel type; and

(3) apply a utilization rate (fuel use per unit of activity).

The exogenous inputs are listed in Table 5.1 with the relevant data sources. Most data are provided by either DRI or NEPP. The electricity prices are computed endogenously by AUSM.

5.3 INDUSTRIAL ENERGY DEMAND

Industrial energy demand plays a dual role in IMS. Industrial electricity demand provides a portion of the driver data for AUSM. Industrial fossil-fuel demand for boilers and process heaters is required as input for ICE and PROMPT. The extent to which these demands are interconnected is modeled by the INRAD module. INRAD is an extension of the previous National Adjustment and Disaggregation (NAD) (Boyd, et al. 1986) module and the industrial-sector implementation of the Argonne Regionalization Activity Module (ARAM) used to provide test data for the development of the individual emissions models (Hanson, et al. 1988a).

INRAD is implemented using a two-equation, constant return to scale (CRTS) generalized Leontief factor-demand system. The two factors in INRAD are fossil fuel and electricity. The CRTS generalized Leontief approach yields equations that predict the factor intensity; i.e., the ratio of the factor input to a measure of output. The variables used to predict the factor intensities are the square root of the ratio of the factor prices, capacity utilization, and technical change variables. The prices included in INRAD are for fossil fuel and electricity, and price indices for capital, labor, and materials are included as well.

The equations are estimated from national energy accounts data for the period 1958-1981.* A separate equation is estimated for eight energy-intensive industry groups (see Table 5.2). These eight groups are derived from seven energy-intensive two-digit standard industrial classification (SIC) industries. For INRAD, only the energy-intensive, basic-materials portion of the two-digit sector is used. A single equation is estimated for all other nonenergy-intensive industries, including the downstream product portions of the seven two-digit industries in Table 5.2.

*Data from 1958-1985 recently became available from the Department of Commerce. The equations are being reestimated with this newer data.

TABLE 5.1 Summary of Driver Data for the Residential and Commercial Energy Model

Sector and Data Set	Element	Time	Unit	Source
Residential:	HOME Model			
Economic inputs	Real disposable personal income	1980-2030, yearly increments	1980$	DRI/RIS
	Population		10^6 persons	DRI/RIS
	Housing starts		10^6	DRI/RIS
	Mortgage interest rates		percent	DRI/MACRO
Energy prices	Distillate fuel oil	1980-2030, yearly increments	1982$/$10^6$ Btu	NEPP
	Residual fuel oil			NEPP
	Natural gas			Gas supply model
	Electricity			AUSM state model
Commercial:	CSEM Model			
Economic inputs	Real disposable personal income	1980-2030, yearly increments	1980$	DRI/RIS
	Population		-	DRI/RIS
Energy prices	Distillate fuel oil	1980-2030, yearly increments	1982$/$10^6$ Btu	NEPP
	Residual fuel oil			NEPP
	Natural gas			Gas supply model
	Electricity			AUSM state model
Other inputs	Acreage of forest land	1980[b]		[a]
	Acreage of agricultural land under cultivation			

[a]Statistical Abstract.

[b]Remains constant from base year (1980).

TABLE 5.2 Energy-Intensive Industry Groups in INRAD

INRAD Industry Group[1]	Description	NEA Sector[2]
20	Food	
22	Textiles	
26U	Basic paper	24020, 24990a
28U	Organics	27010a
	Inorganics	27010b
	Fertilizers	27020
	Plastics & synthetics	28010, 29020, 28990
29U	Petroleum refining	31011
32	Glass & products	35000
	Cement	36010
	Stone & Clay Prods.	36990
33u1	Ferrous metals	37011a, 37990
33u2	Primary aluminum	38040

[1]The INRAD code indicates whether the entire two-digit SIC industry is used or if only the upstream product sector, designated by a "u", is included.

[2]These codes are from the National Energy Accounts industry taxonomy listing. An "a" or "b" after the code number indicates additional disaggregation was performed by ANL.

The national-level equations are implemented at the state level by assuming common price elasticities in each industry, across all states. To preserve the elasticities, a multiplicative benchmark of the national-level equation must be computed based on state-level energy intensities which depend on state-level energy prices. State-level, industry-specific energy prices are input into the INRAD energy intensity equations to compute a state-level energy intensity. Since the goal is to forecast energy use, the benchmarking is done by taking the forecast growth rate in industry output for a state and the growth rate for the corresponding predicted energy intensity and applying these two growth rates to a base-year state-level energy use. The use of growth rates is equivalent to computing a multiplicative benchmark for each state.

INRAD obtains the forecast of state-level industry-specific prices from other modules in the IMS. When running in the annual recursive mode, INRAD takes the average industrial electric prices from AUSM. This procedure is done to account for industry-specific and state-specific base-year differentials and forecast trends in prices, respectively. The industry- and state-specific fossil-fuel price index is constructed by taking 1980 industry-specific expenditure weights for residual oil, distillate oil, natural gas, and coal consumption and weighting the corresponding state-level price forecasts from the IMS price module.

6 POST PROCESSOR SECTOR MODELS

The postprocessor models described below model activities and emissions for the residential, commercial, industrial, and transportation sectors using output from the preprocessors and the annual recursive loop.

6.1 INDUSTRIAL EMISSIONS MODELS

The industrial sector is by far the most diverse sector modeled by the NAPAP energy and emissions integrated model set. The variety of industrial activities and the ways in which this sector affects the energy drivers and emissions are significant. For this reason, the industrial sector is broken down into several component models. These are the ICE model, VOC model, and PROMPT. These three components of the NAPAP model set were originally developed as standalone emissions-forecasting models.

This section presents an overview of the structure, input requirements, approach, and outputs of the models. Special emphasis is placed on the inputs and the type of outputs that may be required for feedback. The models all calculate emissions and control costs for regulatory scenarios. This paper focuses on emissions or their precursor data, energy use, and fuel choice. The ICE model is discussed first, followed by VOC and then PROMPT.

The ICE model is a forecasting model for boiler fuel choice and emissions. The basic drivers in the model are a boiler-fuel forecast and a fossil-fuel price forecast. A variety of policy and forecasting options are also available in the model but are not discussed here. The forecast of the boiler-fuel use is input into the model at the state level for seven industry groups: six are energy-intensive industries (SIC 20, 22, 26, 28, 29, and 33) and the seventh is "other" (South, et al, 1985). The forecasts are at the state level. The ICE model allocates this energy use to a more disaggregate 1980 base-year data base to determine what part, if any, of the boiler forecast constitutes new or replacement boilers.

For new boilers, ICE chooses a boiler fuel and corresponding emission control, if applicable, based on the levelized cost of the various alternatives. To compute the levelized values of the alternative, a fuel price forecast is required. The model considers several fuel types with various levels of sulfur content. They are natural gas, distillate fuel oil, residual fuel oil (four sulfur contents), and coal (up to 11 coal types*). The prices are input at the federal region level.

The industrial VOC model transforms inputs of growth rates for 126 categories of industrial activity into levels of VOC emissions. These growth rates are input at the state level. The model accounts for applicable regulations, including those scheduled to become effective in the future. The model also differentiates between existing sources, retirements, and new sources. The model is a detailed accounting model, whose major inputs are these industrial activity growth rates and the regulatory data. Models of this type are very input intensive (South, et al, 1988). The outputs are estimates of future controlled and uncontrolled emissions.

PROMPT is an emissions accounting model that transforms a forecast of industrial process energy use into the corresponding SO_2 and NO_x emissions. The fuel use inputs are based on the ISTUM II model of industrial process energy use. The relevant industrial processes are aggregated into emission source groups; eight SO_2-producing categories and seven NO_x-producing categories. For each industrial process category, there are up to 10 fuel types. These energy activities are input at the federal region level. The PROMPT model is very input intensive, requiring the use of ISTUM II to generate the inputs or some type of detailed industrial process energy use database.

*These are combinations of sulfur content and Btu content for bituminous and subbituminous coals. Only nine types are used by the model.

The model transforms the inputs of energy use in the various emission source groups for each fuel type and region into an emission level, taking into account applicable regulations. The outputs are forecasts of either SO_x and NO_x emissions at the federal region level for each of the 15 source groups.

6.2 OVERVIEW OF THE CRESS EMISSIONS MODULE

The CRESS emissions module is designed to project emissions estimates for SO_2, NO_x, and VOCs from 1985 to 2030. Estimates for five-year intervals are produced for states, federal regions, and the United States as a whole. CRESS output is aggregated into residential and commercial sectors related to both economic activity and fuel use. For all three pollutants, emissions are reported for the following sectors: (1) commercial/institutional (coal, liquid fuel, gas, wood, and other) and (2) residential (coal, liquid fuel, gas, wood, waste disposal, incineration, open burning, and other). In addition, VOC emissions are projected for these sectors: (1) service stations and gasoline marketing, (2) dry cleaning, and (3) other solvents.

The 1985 CRESS output corresponds to the 1985 NAPAP inventory that serves as the benchmark for the projections. Emissions by the NAPAP Source Classification Code (SCC) are input for states, then projected to future years based on the economic or demographic projections from the DRI regional model or energy data generated by the HOME and CSEM models. In projecting emissions, differences in emission controls associated with new, replacement, and existing equipment are taken into account. The calculations are carried out in two subroutines: a basic one for SO_2 and NO_x and a more detailed one for VOCs.

Emissions of SO_2 and NO_x are generally projected by multiplying the 1985 NAPAP SCC data by the ratio of the driver data value in the projection year to its value in 1985. Emission controls are mandated for a few SCCs, such as large commercial/ institutional boilers. These are modeled by applying to the emission data the ratio of the expected emission factor to the base-year emission factor. The subroutine permits variation in fractions for new and replacement emission sources and in new-source emission ratios by state. However, emission ratios are an average over the projection period and remain constant.

The VOC estimation methodology is similar but allows variation in emission factors over time. Emission ratios are calculated from files of existing emission factors, and new-source and replacement-source factors by state. These latter are input for each five-year projection interval. This procedure allows for considerable flexibility in simulating the effects of VOC control strategies.

6.3 TEEMS

TEEMS is a model system that forecasts transportation activity and the impacts of these activities on the production of emissions of SO_2, NO_x, and VOC that contribute to acid precipitation. The TEEMS submodels input price and activity data from the IMS and output emissions and fuel use data to ECAM. TEEMS incorporates submodels to forecast (see Saricks, 1985, and Vyas and Saricks, 1986):

- All local personal travel, both that occurring within standard metropolitan statistical areas (SMSAs) as defined in 1980 and other (nonSMSA) travel;
- Intercity personal travel by ground and air (business and nonbusiness);
- Commercial and rental automobile and light-truck travel;
- Interurban (including port-to-port) goods movement (coupled with intraurban distribution);
- Other aviation (including general, military, and international travel); and
- The emissions from each of the above activities.

The TEEMS emissions module is MOBILE4. Considerable work has gone into the preparation of speed, temperature and other inputs to MOBILE4.

7 OUTPUT SUMMARY AND FEEDBACK

7.1 EMISSIONS AND COST AGGREGATION MODULE (ECAM)

The ECAM module provides the following functions: (1)Aggregation of gas demands to feed back into the gas supply module; (2) Aggregation of electric rates, fossil fuel prices, electric-utility expenditures, and other variables needed to feed back into the DRI annual macro economic model; (3) Computation of costs and economic welfare losses; (4) Computation of summary results; and (5)Report writing. Aggregating emission results over sectors precludes double-counting emission categories and leaving out major categories. A mapping exists between the SCC in the 1985 NAPAP emission data base and the IMS emission categories.

7.1.1 Base Case Calibration

The report writers start out by attempting to benchmark future trends to a 1985 base year. The 1985 NAPAP data base provides a considerable amount of 1985 base-year information for the IMS. This data base is supplemented by many other data sources for 1985, including EIA's 767, 759, and 423 electric-utility data; U.S. DOC National Energy Accounts, EIA's Manufacturing Energy Consumption Survey, and EIA's State Energy Data System. Unfortunately, good disaggregated industrial data do not exist and one must infer how energy is currently being used in industry. The last ambitious attempt was the 1976 energy consumption data base, which was based on a 1974 survey.

7.1.2 Measurement of Costs

In evaluating the costs in a cost-benefit analysis of a policy, three levels of cost-measurement concepts are provided. (Other work is being sponsored by NAPAP for evaluating the benefits, and similar measurement concepts apply to benefits also.) These levels are as follows:

Direct Costs

Direct costs can often be considered as engineering or financial costs. These include costs of pollution abatement and fuel switching. They can be expressed as (1) the path of outlays over time, (2) the present value of this outlay stream, as a function of the discount rate, or (3) various levelized or annualized cost concepts.

The boundary of the system in which direct costs are considered may sometimes need to be expanded to the whole utility system. For example, given total electricity demand from the system, the criterion of efficiency states that this electricity should be generated at the least total cost. This total cost function can still be viewed as a direct cost. Another important issue regarding direct costs is their distribution. The result of taxes and subsidies, which are transfer payments, is that direct costs to the utility are not the same as direct costs to the nation as a whole. In fact, some pollution-abatement policies propose explicit subsidies or cost-sharing concepts. Thus even direct costs involve both economic efficiency and equity or income distribution.

Economic Welfare Costs

If the mix of goods produced and consumed changes and hence their relative prices change, then the concept of direct costs is no longer sufficient to provide an economic evaluation of a policy. Consumer surplus plus producer surplus is a simple criterion to measure welfare losses in these circumstances. The more precise and general concepts of equivalent and compensating variation are ways to provide welfare measures in dollar terms of changes in the mix of goods. If electricity and gas prices rise, these services and the products based on them or complementary to them will be consumed less. Goods not intensive in these services may be consumed more. A number of computable general equilibrium economic models have been constructed to trace the long-run consequences of these changes. [e.g. Hanson and Alfsen, 1986]

<u>Indirect, Secondary or Macroeconomic Costs</u>

The third category of costs also includes adjustment costs due to sectoral changes, unemployment, inflation, and lack of full utilization of capital.

7.2 ENERGY MARKET EQUILIBRIUM

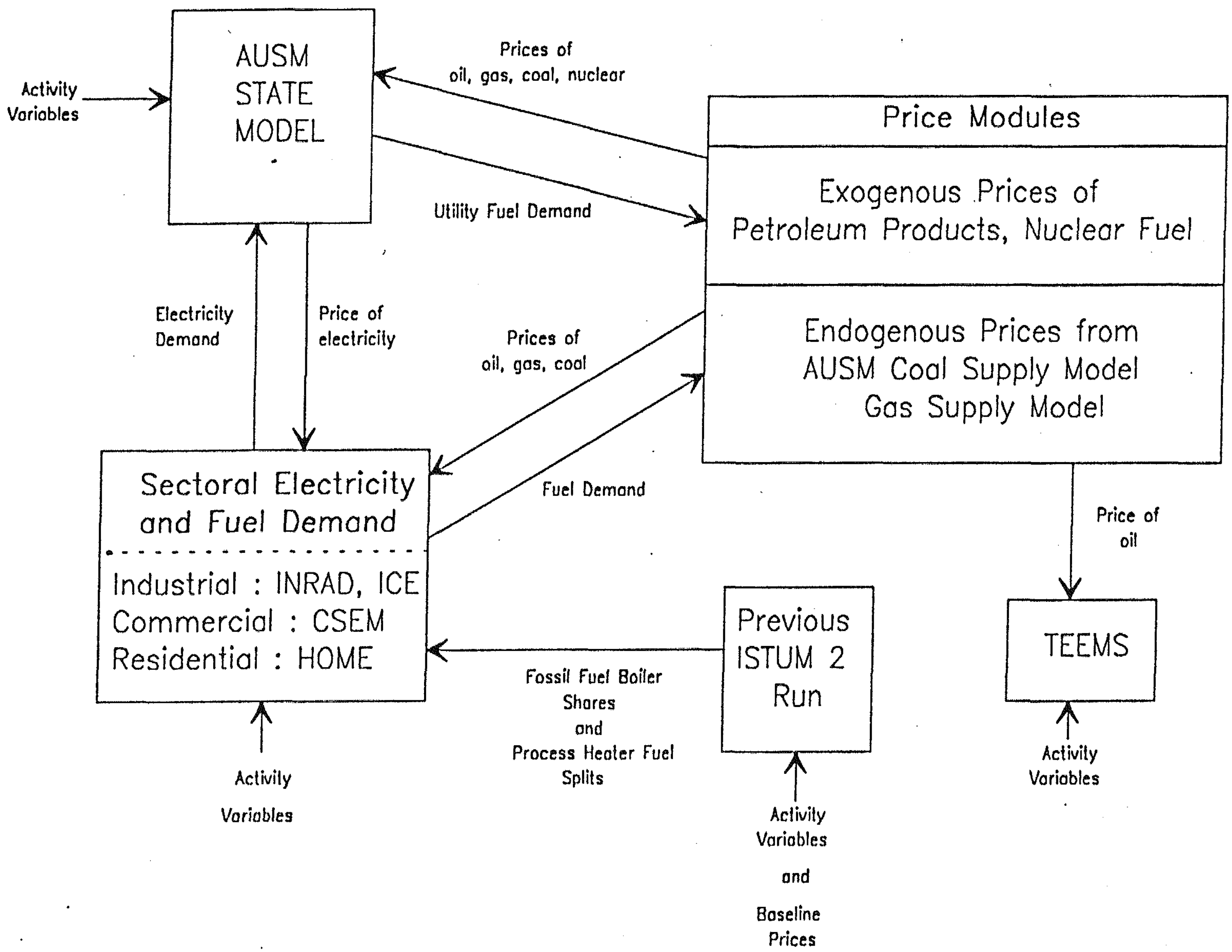
In the integrated model, as in any free-market system, prices play an important role in resource allocation. As shown in Figure 7.1, the price of coal is determined endogenously by AUSM's NCSM, and the wellhead price of natural gas is determined endogenously in the GSM. The prices of petroleum products such as gasoline, residual oil, and distillate oil are determined exogenously by the world oil price. The price of nuclear fuel is also determined exogenously.

These prices, together with activity variables, technology, other input prices, and emission regulations, determine the supply of electricity and the demand for utility fuels in the AUSM state model. The demand for electricity and other fuels by the industrial, commercial, and residential sectors is determined by INRAD, ICE, CSEM, and HOME, using these fuel prices and consumer-activity variables such as consumer income and the output level of final products.

Equilibrium is attained in the coal, natural-gas, and electricity markets as the prices of these fuels are determined endogenously, and will adjust within the model by recursion until the quantity supplied equals the quantity demanded in each market. Since the prices of petroleum products and nuclear fuel are determined exogenously in the model, these markets may not attain equilibrium. The integrated model seeks a partial-equilibrium solution in this sense.

Because the prices of coal, natural gas, and electricity are determined endogenously, the model can be used to determine the impact on these industries of

FIGURE 7.1 Energy Market Balance and the Role of Prices



changes in emissions or other policies in terms of both the prices and the consumption of these fuels. Since the prices of petroleum products and nuclear fuels are determined exogenously, the impact on the consumption of petroleum and nuclear fuel would be determined within the model, but the effect on prices would not.

7.3 MACROECONOMIC AND REGIONAL IMPACTS

The world oil price is an exogenous variable in both the IMS and the DRI macro model. Other macro variables related to the IMS are consumer expenditures and prices for electricity and fuels. Public utility capital investment is an investment variable in the DRI model. Also changes in annual operating and maintenance costs have been modeled by DRI as a subtraction from aggregate supply in the economy.

The national impacts of any specific scenario may often mask the regional disparities. Hence the regional impacts are considered crucial and are modeled explicitly through the DRI/RIS model, which, in turn, depends on the values of selected output variables from the DRI annual macroeconomic model.

8 OVERVIEW OF COMPUTER IMPLEMENTATION

The implementation goal of the integrated model is to provide a portable system that can be used and run by members of the emissions modeling community. The integrated model has been assembled from several independently developed activity and emissions models. Computer development of the integrated model has proceeded in three primary phases. Phase 1 encompassed the initial model development that took place under several language and operating-system environments over the past 10 years. In Phase 2, the present state, most of these models have been ported to the UNIX operating system. The models were then modified to provide for either simultaneous or iterative interaction between models during simulation runs. At present, the integrated system operates primarily on a SUN UNIX workstation. In Phase 3, those remaining models not operating under the UNIX operating system will be ported to it, allowing the complete system to run on a single, independent UNIX machine.

The code of the AUSM state loop was written by several teams on IBM mainframes using FORTRAN. It was ported to the SUN and required few substantive changes. The changes can be characterized as system-specific syntax adjustments. Redefinitions of file names were required by the UNIX operating system to allow the program to gain access to its data files on the SUN system. Variable declarations were recoded to conform to SUN FORTRAN's stricter implementation of American National

Standards Institute (ANSI) restrictions. Because the AUSM interacts with other elements of the system through certain of its common blocks being included in those other models, AUSM had to be called as a subroutine (thus allowing common blocks to be shared between models).

For some models substantial changes to an existing model were necessary. A good example of recoding an existing algorithm is characterized by the gas demand module. This module was originally written as a set of macros in a Lotus 1-2-3 spreadsheet. To allow the model to operate in the integrated framework it was rewritten in FORTRAN. The function and structure of the model was retained while it was recoded in its entirety. The other cases where substantial changes were made in an existing model occurred when a model's structure was incompatible with the AUSM state loop, which is the integrated model's foundation program. An example is the commercial and residential demand models, originally written with a structure that operated on four census regions for each year. To allow operation with the AUSM state loop, CSEM and HOME had to be restructured to operate on a single state through the end of the forecast period before beginning on the next model region (state). Most of the original code was retained and executes the original algorithms; the control structures and some of the input data sets were changed.

The final set of work consists of new programs. Vital to the overall model is the set of control programs that call the various members of the integrated set and permit the exchange of data and parameters. The control program is written in C because that language is used by the UNIX operating system. Another substantial member of the integrated model is INRAD, the industrial sector demand model. INRAD was written specifically for the integrated model in FORTRAN on the SUN.

Other than the use of C for control routines that interface to the UNIX operating system, only two exceptions exist to the use of FORTRAN as the language of implementation. These are the DRI macroeconomic model and the AUSM national loop. The AUSM national loop is written primarily in FORTRAN, but substantial data handling is done using a FORTRAN-compatible language called DATAFORM, which is proprietary software. These routines will be recoded in FORTRAN to enhance portability and reduce costs. Because DATAFORM runs only on IBM mainframes, the present disk storage and operating costs of the integrated model are higher than they would be if this program were running on a SUN workstation. In addition, the inclusion of a model running under a different operating system complicates the exchange of data between program subroutines. The other exception to the use of FORTRAN is the DRI macro model, which exists as binary executable code that must run on a high-speed IBM/PC-compatible microcomputer. Because ANL has many such systems integrated into its SUN network, this requirement presents no difficulty at present, but it does limit portability to other sites that might want to run the integrated model. DRI has informed us that the macro model can be ported to a UNIX workstation (or other environment) if necessary.

9 DESCRIPTION OF SELECTED PRELIMINARY TEST RESULTS

9.1 SOME RESULTS FROM RUNNING THE DRI MACRO MODEL

The test results from the simulation of the DRI macroeconomic model over the period 1987-2030 that included the preliminary NEPP7 assumptions are provided here. Economic growth is expected to proceed at a fairly steady pace throughout the simulation interval, but this pace is expected to slow down from 2010 onward. Instead of the 2.4% average annual growth expected through 2010, economic growth will average about 1.6% growth per year during the final 10 years of the simulation. This decline in the growth rate of output is attributed primarily to reduced rates of population growth. Figure 9.1 shows how real GNP and its components behave over the course of this test simulation. Because this was only a test, the target GNP path from NEPP was followed reasonably closely, but full fine-tuning for an exact tracking was not done in this test. GNP is simply the amount spent on consumption, investment, and government, with an adjustment for net exports. Figure 9.2 shows how the population growth rate and the size of the labor force behave over the course of the simulation.

By and large, the components of real GNP, behave in ways similar to real GNP growth over the forecast interval. However, business fixed-investment grows at a rate that is nearly double that of GNP throughout the simulation horizon, averaging about 5% percent real growth per year from 1988 to 2010. Perhaps reflecting declining rates of population growth, residential investment shows a significantly slower growth rate than that of business fixed-investment, averaging a 0.7% throughout the entire forecast interval. Figure 9.3 illustrates these trends in business fixed-investment and residential investment.

Government spending on the federal, state, and local levels grows at similar rates throughout the simulation, with the federal share of total government spending averaging 1.3% growth throughout the simulation. The economy finally beings to run trade surpluses beginning in the early to mid 1990s.

Figure 9.1 Real GNP and Components PNEPP-7 Macroeconomic Forecast

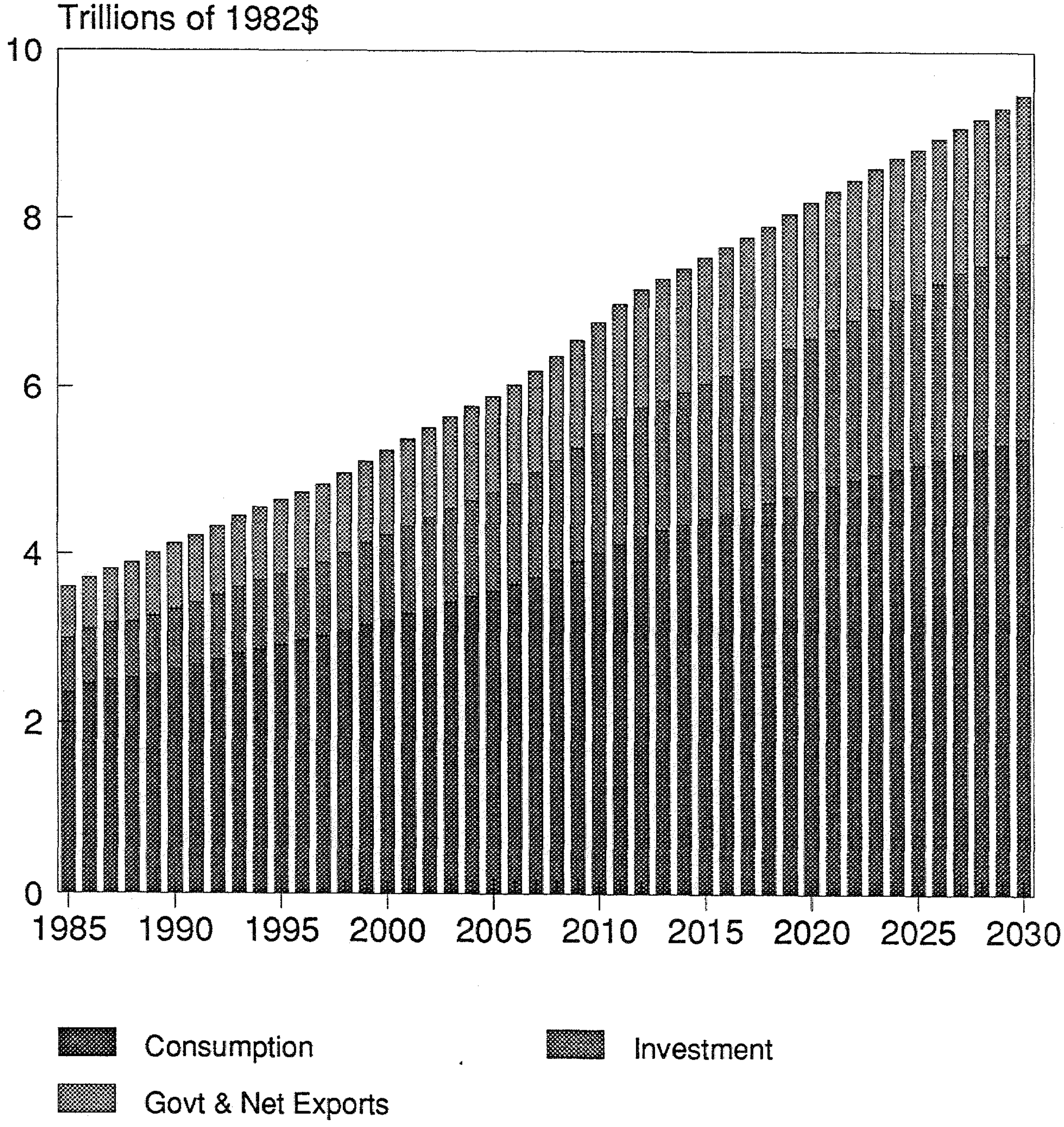


Figure 9.2 Population and Labor Force
PNEPP-7 Macroeconomic Forecast

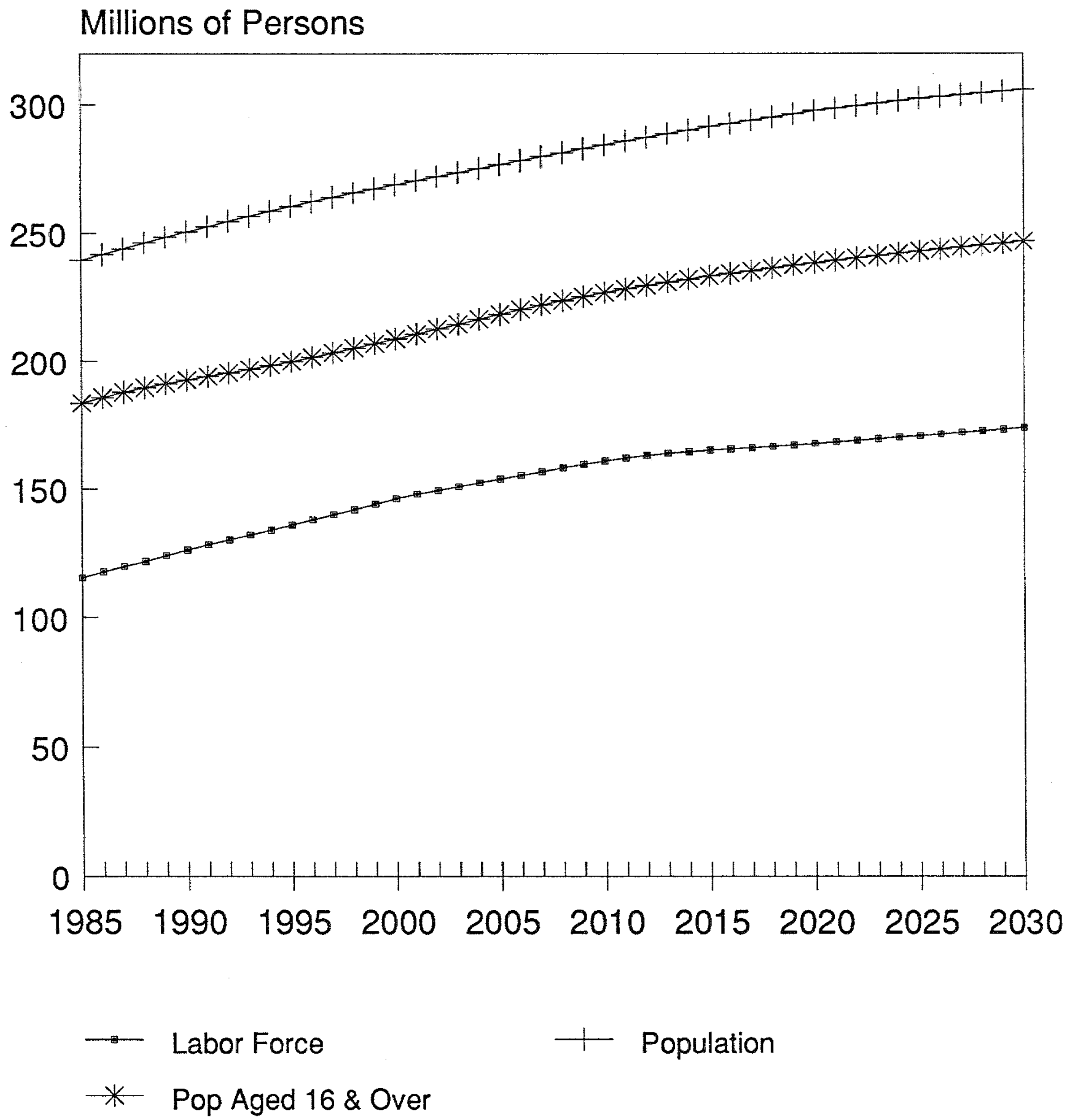
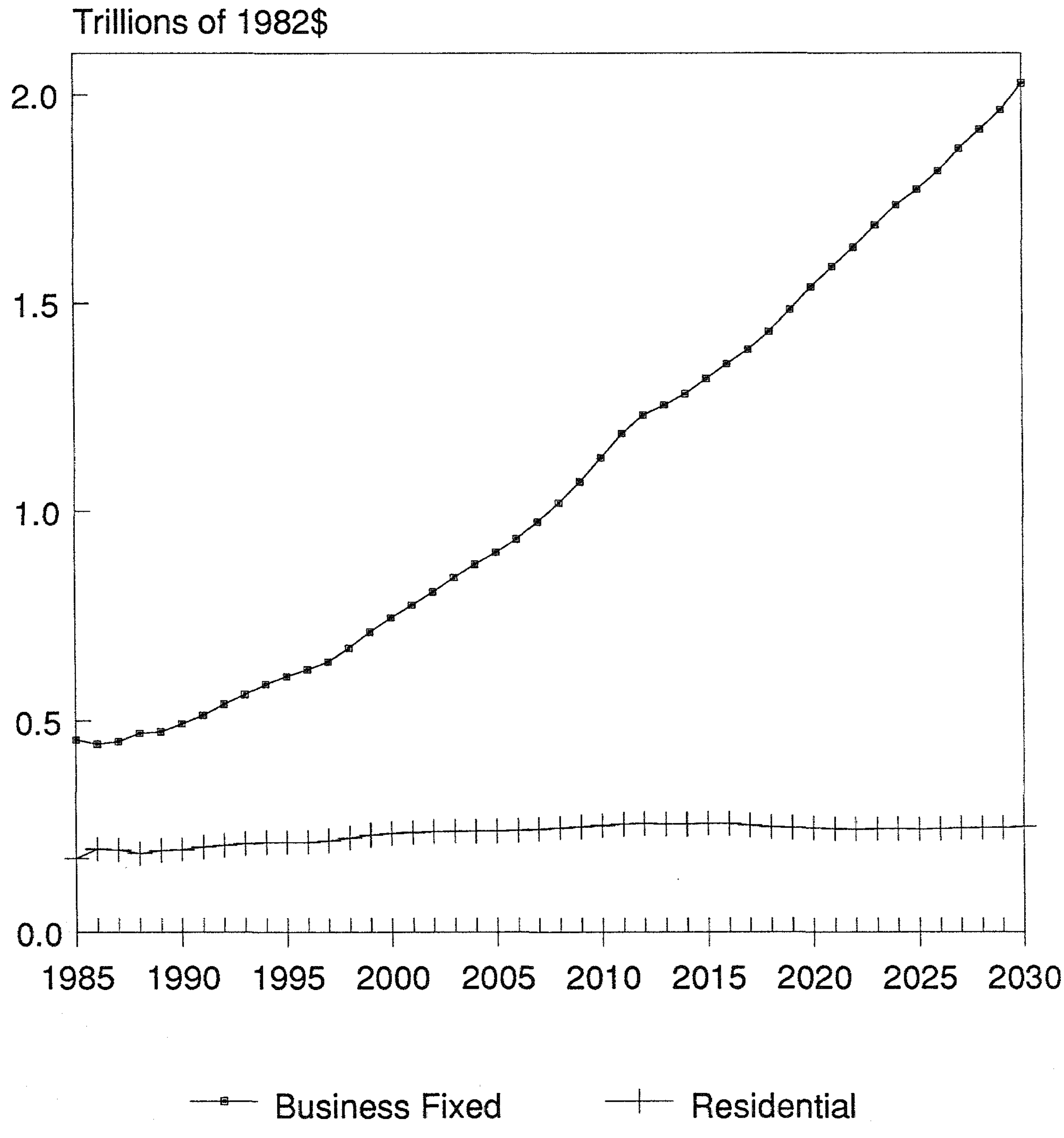


Figure 9.3 Investment Spending
PNEPP-7 Macroeconomic Forecast



The share of foreign trade in GNP is expected to grow continually throughout the simulation period. Both exports and imports are expected to grow relative to GNP. Exports will grow from about 10% to just under 22% of GNP. Imports will grow to a similar degree, from a little over 12% in 1988 to about 20% of GNP by 2030. These patterns for nominal export and import shares are very close to those provided by DRI in their reference case of the extended annual model.

Experimental sensitivity tests with the DRI Macro Model indicated an average decrease in GNP of 0.8% compared to the reference case due to higher prices for electricity and natural gas.

9.2 RESULTS OF REGIONAL SCALING

The scaling methodology described in Section 4.2 was implemented successfully, and the resulting projections of the relevant regional variables were consistent with the overall macro projections used for model set testing. Furthermore, the regional projections were extended to 2030 to be consistent with the rest of the IMS. Figures 9.4 and 9.5 illustrate sample results. As an example of the effects of scaling on a quantity variable, Fig. 9.4 shows how the projections for employment in the paper industry in Illinois were affected by the scaling. The scale factor was determined so that the sum of paper industry employment in all states is equal to total U.S. paper industry employment as projected by the DRI Macro Model. Fig. 9.5 shows the effects on an index number variable, where the scaling is accomplished by the use of differential growth rates.

9.3 RESULTS FROM THE GAS SUPPLY MODEL

Figure 9.6 shows the predicted prices in 1982 dollars of wellhead natural gas from the gas supply model under two scenarios. The lower line shows the price path of natural gas, assuming the demand for natural gas is as predicted by the *National Energy Policy Plan Projections*, Draft 2, of January 9, 1989. The higher line assumes a 20% increase in natural-gas use by electric utilities. As Fig. 9.6 indicates, this increased gas use has only a modest impact on wellhead prices. These results imply that increased conversion to natural gas by electric utilities may not substantially increase natural-gas prices.

Figure 9.4 Projected Employment in Paper Industry in Illinois

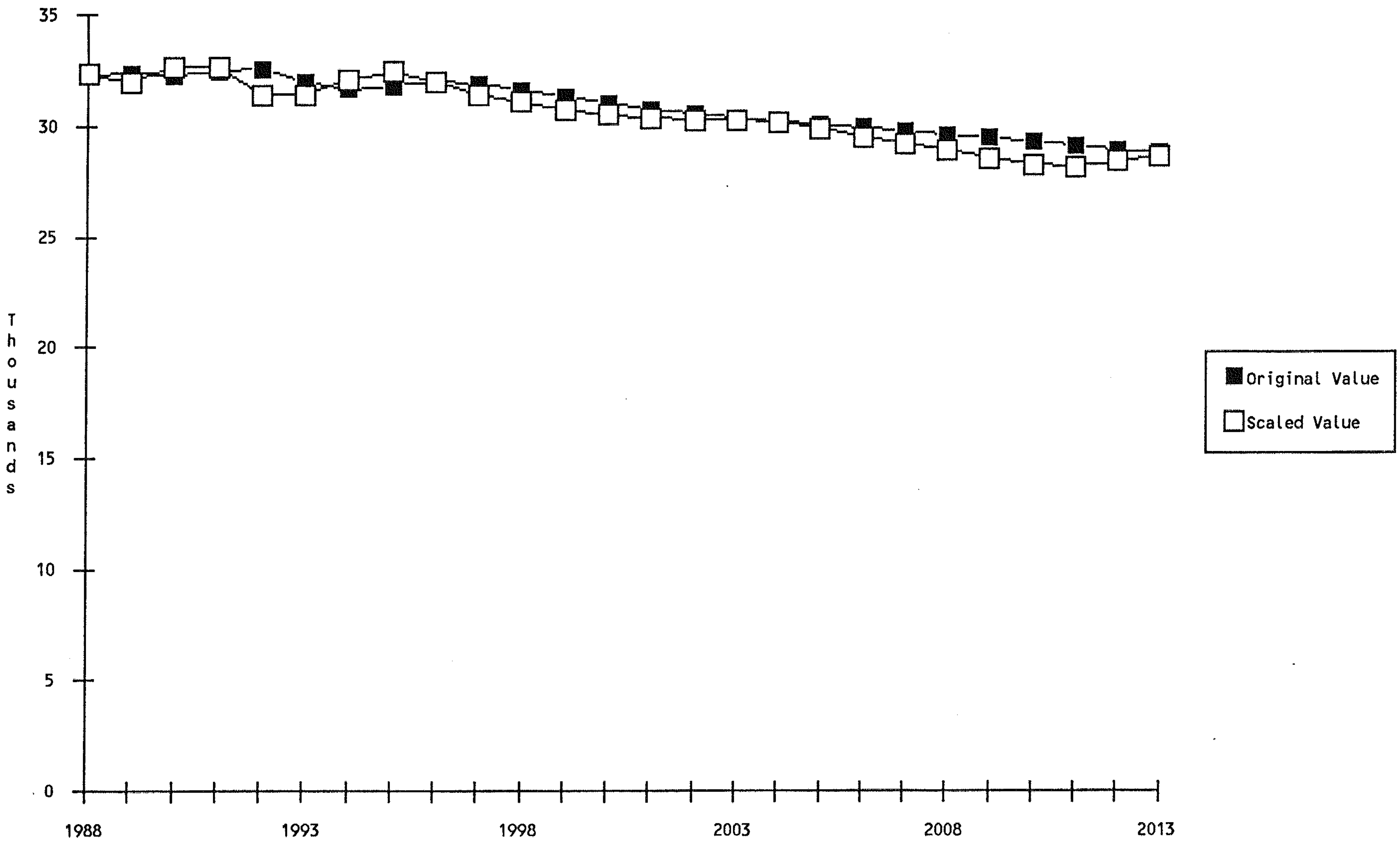


Figure 9.5 Projected Manufacturing Production Index for Paper Industry in Illinois

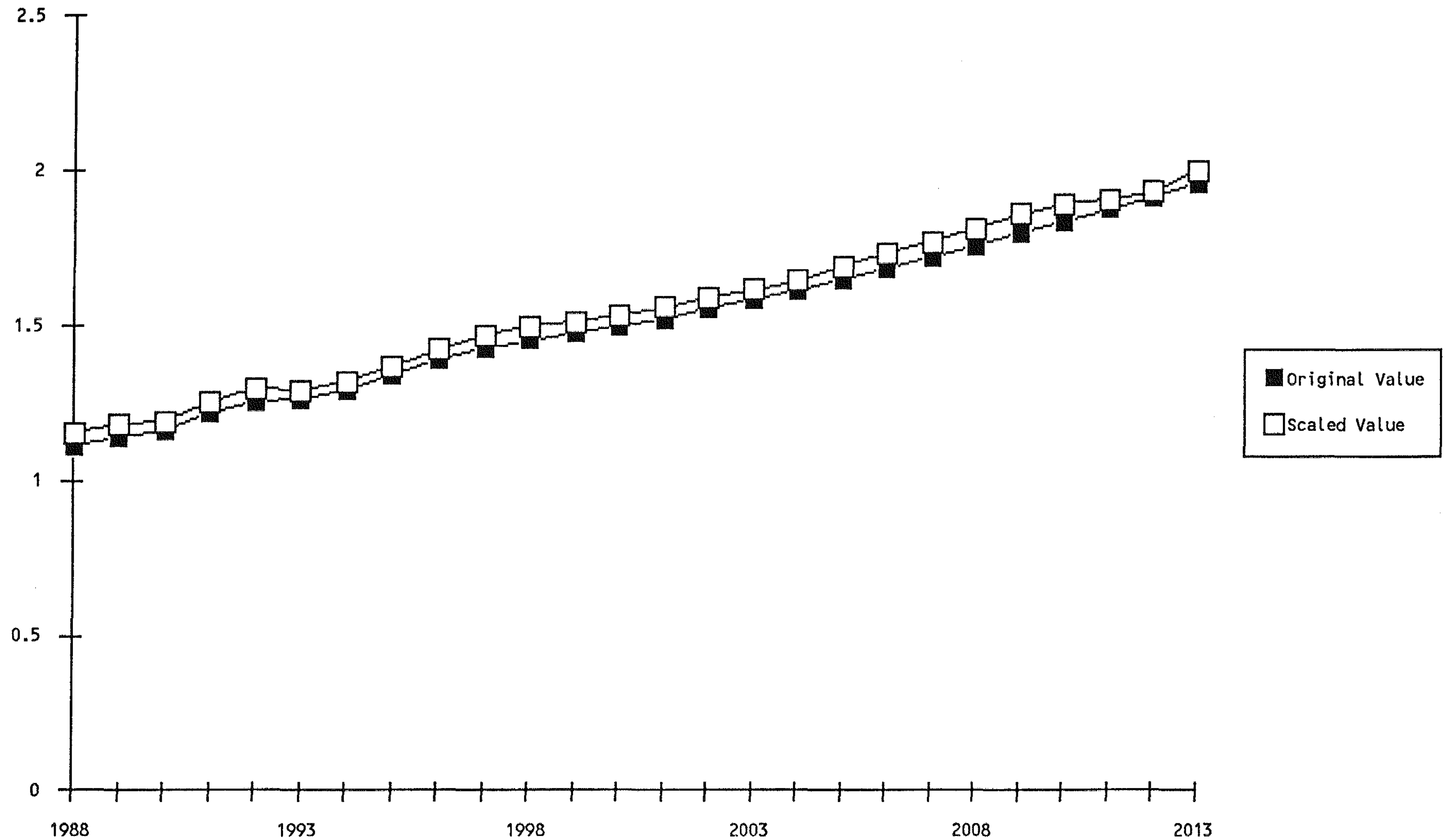
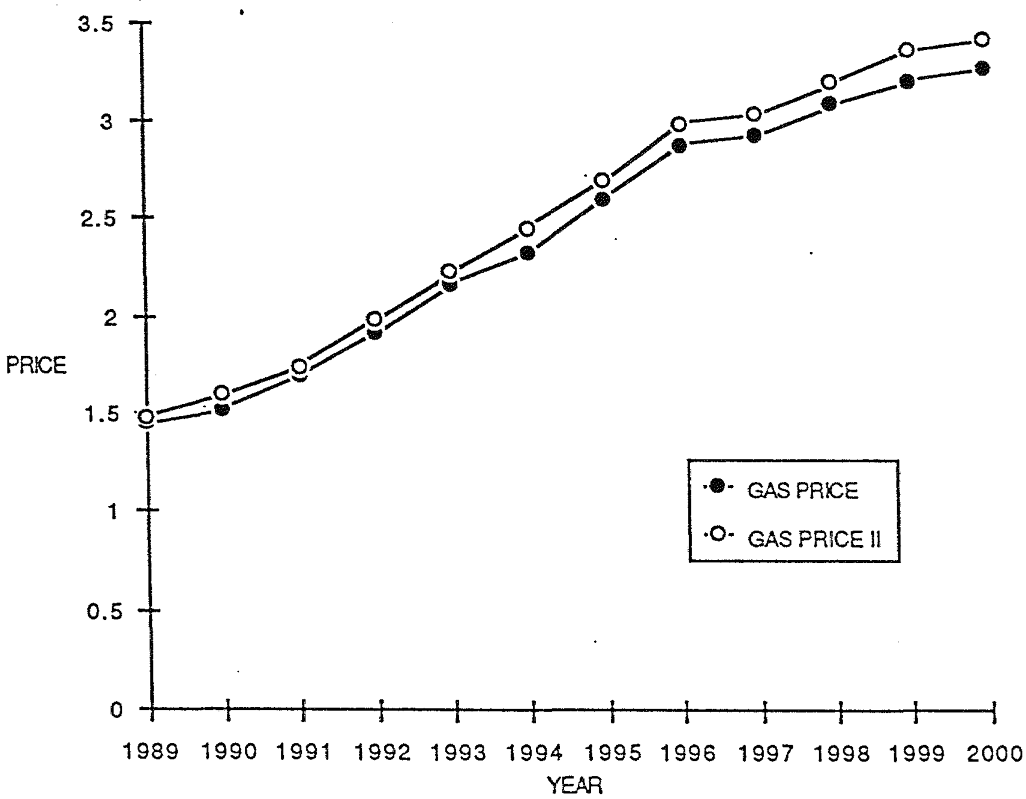


FIGURE 9.6 Gas Prices From the Gas Supply Model in 1982 Dollars Per MCF



9.4 RESULTS FROM NCSM

As an example of the kind of data that the NCSM generates, Table 9.1 provides coal prices for bituminous coal in Ohio for the period 1980-2005. Delivered coal prices for all three types of coal, by sulfur category and by state are generated by CSM as part of the national loop of AUSM. In response to price changes, coal movements between supply regions are also provided, as shown for Ohio in the year 2000 in Table 9.2. However, there is considerable uncertainty in predicting supply regions, since the coal market is very competitive and different supply regions may have similar costs.

10 SUMMARY

This paper describes the NAPAP Integrated Model Set and provides some preliminary results. This model set has been constructed to provide a consistent assessment of the impacts of control policies for the precursors of acid deposition. It is intended to replace limited sectoral studies with a model system that will determine the effects of control policies throughout the economy.

TABLE 9.1 Delivered Prices of Bituminous Coal in Ohio by Sulfur Content Category (SO2CAT) for 1980-2005 (1980$/MMBtu)

SO2CAT*	1980	1985	1990	1995	2000	2005
1	2.33	1.84	1.35	1.51	1.66	1.76
2	2.22	1.77	1.31	1.47	1.62	1.72
3	1.87	1.53	1.18	1.34	1.49	1.59
4	1.61	1.38	1.15	1.28	1.40	1.51
5	1.55	1.33	1.11	1.23	1.35	1.46
6	1.53	1.30	1.06	1.19	1.31	1.41
7	1.47	1.25	1.03	1.15	1.27	1.38
8	1.20	1.10	1.00	1.11	1.22	1.32
9	1.35	1.11	0.88	1.03	1.18	1.29
10	1.52	1.19	0.86	1.02	1.17	1.28
11	1.30	1.07	0.84	0.99	1.15	1.26

*Sulfur categories range from the lowest sulfur to the highest sulfur.

TABLE 9.2 Bituminous Coal Movement in Ohio for the Year 2000 (1000 MMBTU)

	Supply Regions						
SUL*	Other	W.V. (Panhandle)	W.V (SW)	Ohio	KY East	WYO	Total
3	36,854	0	4,632	0	10,655	0	52,141
4	37,783	0	80,334	0	0	0	118,117
5	122,076	0	0	0	16,348	0	138,424
7	215,527	0	206	0	0	0	215,733
8	68,983	0	0	0	0	0	68,983
9	84,206	0	0	75,605	0	0	159,811
10	73,627	135,982	0	155,740	0	0	365,349
11	110,557	0	0	0	0	0	110,557

*Sulfur categotries range from lowest to highest.

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