CONF-900801--29

DE90 017673

AN INTEGRATED ACID PRECIPITATION POLICY AND ENERGY MARKET MODEL

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ABSTRACT

The use of disparate and detailed engineering and economic models is often necessary for environmental policy analysis and forecasting. However, to conduct consistent forecasting and policy analysis over all economic sectors these models must be coordinated into a consistent model set. One approach is the NAPAP Integrated Model Set, a collection of engineering, emissions-forecasting, and energy-market models that is driven by and interacts with other energy-market and economic models.

1. INTRODUCTION

To make forecasts and analyze policies that involve complex systems, such as those involving interactions among energy, environmental, and economic factors, a set of highly specialized models is desirable. The difficulty comes in integrating this set of models into a consistent framework where important interactions are represented. This is a different type of task than developing a single purpose model. In particular, the genesis and the approach of these specialized models may be different. The task of integrating these disparate models into a consistent set, eliminating overlap, and establishing critical information flows and feedbacks is a project in itself.

Models may have an engineering, economic/statistical, or hybrid approach, depending on the focus of the forecasting and analysis they were developed to address. For example, the specific task of modeling and analyzing policies designed to control environmental emissions must be closely tied to the state of current and emerging technology. Therefore models that consider the costs and consequences of pollution controls tend to be highly specialized, with detailed engineering specifications. Nevertheless, these models require driver data (i.e., linkages) from energy market and economic models in order to run.

This is the case for the set of models collected for use in the United States National Acid Precipitation Assessment Program (NAPAP). These models are mostly engineering-process oriented or use other engineering notions to develop environmental emissions forecasts, control strategies, and cost estimates. In some cases the models may play a key role in the energy market (e.g., represent a specific demand sector). In one important case, the model that is the focus of critical environmental policy analysis addresses a significant part of the energy market (the electric generating sector).

The NAPAP Integrated Model Set (IMS) has been developed for use in the NAPAP assessment planned for 1990 (NAPAP 1989a). 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.

2. OVERVIEW OF THE INTEGRATED MODEL SET

Figure 1 presents a simplified view of the structure of the IMS. 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 sectoral emission models, and Step IV is aggregation, feedback, and report writing.

A model run begins in Step I using data on a target GNP growth path, exogenous 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.

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, interstate transfers of electricity, and state emission caps. The Gas Supply Model (GSM) determines a price of natural gas, given gas demand. The exogenous world oil price is disaggregated into fuel types and regionalized based on an analysis of historic price 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 (INRAD) model, the Commercial Sector Energy Model by State (CSEMS), and the Household Model of Energy by State (HOMES) to determine the demand for electricity and fuels by these sectors. The annual electricity demand data are sent to the AUSM state loop to form the annual recursive loop. Electric rates are calculated by AUSM using a revenue requirements approach. Equilibrium in the coal market is obtained via an iterative approach. The coal demands from AUSM are passed to the Coal Supply and Transportation Model (CSTM), which updates the coal prices. AUSM and CSTM iterate until the demands for coal by coal type are stable.

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 (VOC) model calculates industrial emissions of nonmethane

FIGURE 1 OVERVIEW OF THE INTEGRATED MODEL SET

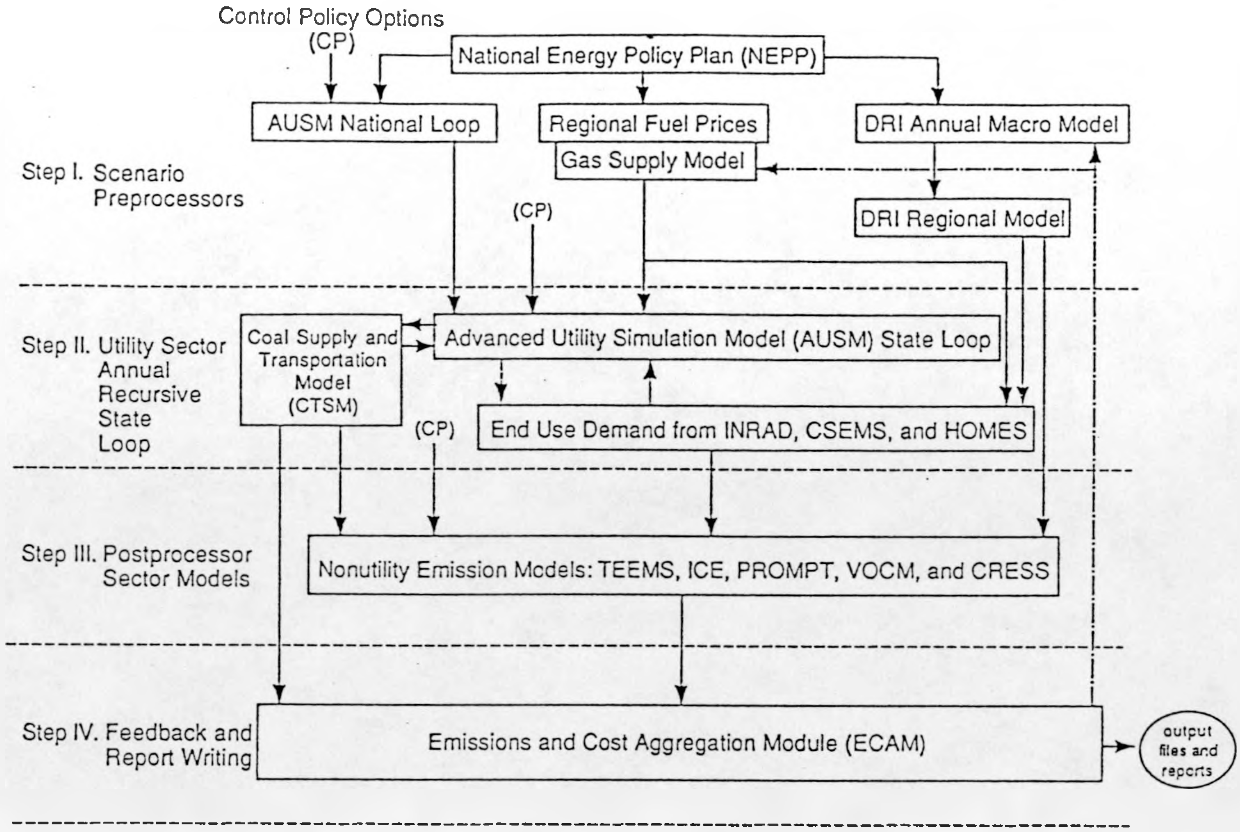
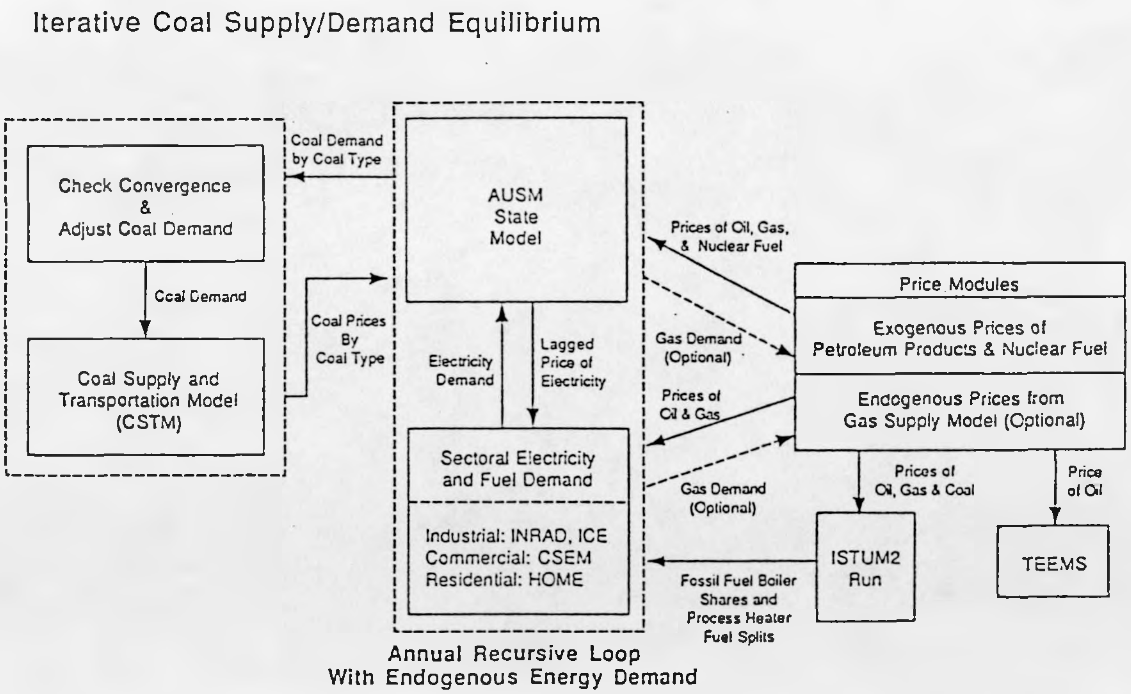


FIGURE 2 ENERGY MARKET BALANCE AND THE ROLE OF PRICES



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 recursion if necessary to attain a consistent forecast.

3. NEPP AND THE NAPAP REFERENCE SCENARIO

Forecasts of energy prices and economic activity forecasts from NEPP provide many of the required scenario inputs for the NAPAP Reference Scenario (NRS). These are described in NAPAP SOS/T Report No. 26. The provision of driver data on supplemental electricity supply at the state level is described in Hanson et al. (1988). Many of the NRS electric utility supply factors are determined by a joint DOE/EPA agreement. 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.

The IMS is capable of simulating many types of policies. These policies can potentially affect all four sectors modeled in the IMS and a wide range of sources within these sectors. Proposed emission control policies to be modeled include: fuel switching, forced scrubbing, clean coal technologies, emission taxes, tradeable permits, phased policies, and policies that give different weights to reductions in SO_2, NO_x and VOC. Some of these policies, such as intrastate or interstate emissions trading, will require some postprocessing of model runs to calculate efficient, least-cost trades among emission sources (e.g., see Streets et al. 1983).

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 forecast from the DRI macro and regional models. The AUSM national loop is a linear program that 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 oil market and the gas market.

4.1 DRI Annual 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) required by NAPAP. It also provides sufficient industry-specific detail to conform to the input requirements of the remaining components of the IMS.

NEPP specifies information on the growth in 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 the economic growth provided by the NEPP forecast. The main variable that DRI uses to adjust its 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 IMS require regional and industry-specific drivers, the output from the DRI macroeconomic model is fed into the DRI regional model.

4.2 DRI Regional Information Services Model

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. For the IMS, 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 variables from the January 1989 regional simulation have to be scaled to the forecasts from the DRI annual macroeconomic model. The scaled variables were extended to 2030 using growth rates obtained from the macro model.

4.3 AUSM National Loop

The AUSM national loop is a linear programming 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 and interstate power transfers.

The national loop is composed of two basic modules: the multiperiod, multistate (MPMS) programming module and the national coal supply module (NCSM). 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 runs for 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. 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 next section.

4.4 The Gas Supply Model

The purpose of the Gas Supply Model (GSM) is to integrate the U.S. domestic natural gas market into the NAPAP Integrated Model Set. The GSM 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* (DOE 1989). In the integrated system, natural gas demand is the sum of electric utility demand from AUSM, industrial demand from the 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 GSM 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 a 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 by the GSM will be used in the price module to determine natural-gas prices for each state and for each final-user class by using transmission and distribution costs forecast by the Gas Research Institute (Holtberg et al. 1988).

4.5 Other Fuel Prices

Prices for fuels other than coal or natural gas are determined exogenously. Historical state prices of all fuels used in the residential, commercial, industrial, transportation, and utility sectors were obtained from EIA reports. Projected national average sector prices for petroleum prices were obtained from the Office of Technology Policy's *National Energy Policy Plan Projections, Draft 2* (DOE 1987). Projected national average nuclear fuel costs were obtained from an input to EIA's *Annual Energy Outlook* for 1989 (DOE 1989).

These projected national average sector prices were converted into projected state sector prices using a function based on the mean difference between the state and national price for the fuel between 1980 and 1986 and a weighting factor that assumed the regression of these state prices toward the national mean.

5. INTEGRATED UTILITY SIMULATION MODEL

The Integrated Utility Simulation Model (IUSM), described in this section, is based on the AUSM state model and CSTM. It forms the core of the IMS. The price and activity data from the preprocessors in Step 1 are provided to IUSM 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. Equilibrium between utility coal purchases and the coal market is obtained via an iterative method. The AUSM state model computes utility coal demand for a given forecast of coal prices. Coal demands for each of over a dozen coal types are then adjusted and passed to the CSTM. CSTM computes a new set of least delivered coal prices and regional coal production patterns. These new prices are then used by AUSM and iteration continues until the coal demands are stable.

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 electric rate schedules. These rate schedules are based on historical data in the first year, then are updated using information from the finance module. The AUSM demand module has been modified to specify 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, CSEMS, and HOMES 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. Hence, overall consistency in the energy forecast is maintained for 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.

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 emissions 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 to (1) 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) enhance their fuel-substitution specification. To project fuel consumption for each end-use, the models follow three basic steps. First, update the basic sectoral activity variable, floorspace in the commercial sector, and housing stock in the residential sector. Second, adjust the share-of-activity variable using each fuel type. Third, apply a utilization rate (fuel use per unit of activity).

5.3 Industrial Demands

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 INRAD.

INRAD is implemented using two equations based on a constant return to scale (CRTS) generalized Leontief factor-demand system (Deiwert and Wales 1987). The two factors in INRAD are fossil fuel and electricity. The equations are estimated from National Energy Accounts data for the period 1958-1985. A separate equation is estimated for eight energy-intensive industry groups. A single equation is estimated for all other nonenergy-intensive industries. 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 is computed based on state-level energy intensities, which depend on state-level energy prices. 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.

5.4 Coal Market

The coal market in IUSM is modeled by CSTM (EIA 1988). CSTM models the supply of coal from 32 supply regions and up to 30 coal types (5 heating values and 6 sulfur contents). Delivered prices are modeled by an abstract rail/water network connecting the 32 supply centroids with 44 domestic demand centroids. The coal supply curves in CSTM are piecewise linear approximations of the step function supply curves generated by DOE's Resource Allocation and Mine Costing Model (RAMC).

CSTM provides AUSM a file of lowest delivered coal prices and characteristics for each region and coal type, based on the previous iteration's coal demand. A convergence algorithm updates the coal demand at each iteration, until the coal demands from AUSM, based on the CSTM price files, are stable from iteration to iteration.

6. POSTPROCESSOR SECTORAL MODELS

These model activities and emissions for the residential, commercial, industrial, and transportation sectors use output from the preprocessors and the annual recursive loop. The industrial sector is by far the most diverse sector modeled by the NAPAP IMS. 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: the ICE model, VOC model, and PROMPT. These three components of the IMS were originally developed as standalone emissions-forecasting models. They all calculate emissions and control costs for regulatory scenarios.

The ICE model is a forecasting model for boiler fuel choice and emissions. The basic drivers in the model are regional boiler-fuel and fossil-fuel price forecasts from INRAD and the price modules, respectively. The industrial VOC model transforms inputs of growth rates for 126 categories of regional industrial activity into levels of VOC emissions. These activities are largely derived from the DRI macro and regional forecasts, with some appropriate adjustments. 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 commercial and residential emissions module CRESS is designed to project emissions estimates for SO_2, NO_x, and VOCs from 1985 to 2030. The module uses fuel-use projections from CSEMS and HOMES, economic-activity projections from DRI, the NAPAP emissions data base, and assumptions about engineering controls and emission rates to forecast these pollutants.

TEEMS is a model system that forecasts the transportation sector activity and the impacts of these activities on emissions of SO_2, NO_x, and VOCs. Price and activity data from the IMS are inputs to the TEEMS submodels and emissions and fuel-use data are output. TEEMS incorporates submodels to forecast all local personal travel; intercity personal travel by ground and air, commercial and rental automobile and light-truck travel, interurban 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. For a more detailed description see Saricks (1985) and Vyas and Saricks (1986).

7. FEEDBACK

In the integrated model, as in any free-market system, prices play an important role in resource allocation. As shown in Figure 2, 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 factors, 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 IMS 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 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.

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.

9. COMPUTER IMPLEMENTATION

Since the models all have different development backgrounds and structures, the environment to integrate them in is important. A UNIX platform, specifically a network of SUN workstations, was found to provide the most flexibility for the task. UNIX shells were written to execute the modules and control the input/output file structure of the system distributed across three different SUN processors. For model components implemented for personal computer only, a network file system allows the UNIX system and the PC's to share common files. Since QA of the scenarios and analysis requires operation of the modules in both an integrated and standalone mode, the UNIX shells have been structured to easily allow for this. The shell scripts also track the scenario specific inputs and output reports. Run times range from 3 to 4 hours for a single iteration of IUSM. Postprocessor model run times range from 1 minute to several hours (e.g., PROMPT and ICE, respectively).

10. SUMMARY

This paper describes the implementation and development of an integrated set of models through the example of the NAPAP IMS. 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 myopic sectoral studies with a model system that will determine the effects of control policies throughout the economy.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support and assistance of the Assistant Secretary for Fossil Energy, Office of Planning and Environment, U.S. Department of Energy, under contract W-31-109-Eng-38, and the guidance of the project manager, Edward C. Trexler. Greatly appreciated has been the excellent work on various parts of the Integrated Model Set (IMS) by Gordon Lurie, C. Yuen, Ron Fisher, Amit Bando, Brian Edwards, Cary Bloyd, Dan Miller, and Guy Pandola in the Energy Policy Section at Argonne. Comments by David G. Streets, Director of the Policy and Economic Analysis Group, and Marylynn Placet have also been helpful. The models of the utility sector (AUSM) and industrial sector (ICE, PROMPT, VOC) were developed by contractors to the U.S. Environmental Protection Agency, Larry Jones, manager.

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