Model Documentation

Renewable Fuels Module

of the National Energy Modeling System

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1. Renewable Fuels Module Introduction

Purpose of This Report

This report documents the objectives, analytical approach, and design of the National Energy Modeling System (NEMS) Renewable Fuels Module (RFM) as it relates to the production of the 1995 *Annual Energy Outlook* (AEO95) forecasts. The report catalogues and describes modeling assumptions, computational methodologies, data inputs, and parameter estimation techniques. A number of offline analyses used in lieu of RFM modeling components are also described.

This documentation report serves two purposes. First, it is a reference document for model analysts, model users, and the public interested in the construction and application of the RFM. Second, it meets the legal requirement of the Energy Information Administration (EIA) to provide adequate documentation in support of its models (Public Law 93-275, Federal Energy Administration Act of 1974, Section 57(b)(1). Such documentation facilitates continuity in EIA model development by providing information sufficient to perform model enhancements and data updates as part of EIA's ongoing mission to provide analytical and forecasting information systems.

Renewable Fuels Module Summary

The RFM consists of six analytical submodules that represent each of the major renewable energy resources—wood, municipal solid waste (MSW), solar energy, wind energy, geothermal energy, and alcohol fuels. The RFM also reads in hydroelectric facility capacities and capacity factors from a data file for use by the NEMS Electricity Market Module (EMM).[1]

The purpose of the RFM is to define the technological, cost and resource size characteristics of renewable energy technologies. These characteristics are used to compute a levelized cost to be competed against other similarly derived costs from other energy sources and technologies. The competition of these energy sources over the NEMS time horizon determines the market peentration of these renewable energy technologies. The characteristics include available energy capacity, capital costs, fixed operating costs, variable operating costs, capacity factor, heat rate, construction lead time, and fuel product price.

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[1]Hydroelectric capacity additions and capacity factors are derived from EIA survey data. Although the RFM reads these data for use by the EMM, the data reside in the EMM utility plant file, an exogenous input file that provides plant-specific construction, cost, and operating parameters. The utility plant file is described in the EMM documentation report. "Since hydroelectric power is not competed against any other energy form for utility capacity expansion, and all the hydroelectric generation is consumed because it is generally the lowest cost, there is not need to have an interactive hydroelectric submodule. It was determined that a data file with maximum capacity, capacity factors, and the other items contained in the file would most accurately represent hydroelectric power in NEMS."

Currently, the RFM is structured principally to provide the EMM with technology and cost data for central station electric generation facilities. One exception is the MSW Submodule, which generates MSW energy consumption values for several end-use demand models along with the EMM. However, the demand models are not currently configured to access these data. Another exception is the Biofuels Submodule, which provides ethanol supply curves for the Petroleum Market Module (PMM).

Other renewables modeled elsewhere in NEMS include the biomass in the industrial sector, wood in the residential sector, geothermal heat pumps in the residential and commercial sectors, and solar hot water in the residential sector. Thus there are several areas, primarily dispersed application, that are not represented in NEMS. This includes direct applications of geothermal heat, several types of solar thermal use, and photovoltaics. For the most part, the expected contributions from these sources are small; however, there are preliminary plans to add many for future analyses.

The number and purpose of the associated technology and cost characteristics varies from one RFM submodule to another depending on the modeling context. For example, renewable resources such as solar, wind, and geothermal energy are not fuels; rather, they are "costless" inputs to electricity or heat conversion processes. Consequently, the Solar, Wind, and Geothermal Submodules do not provide fuel product prices. As another example, the MSW Submodule's capital and operating cost characterization is used by the NEMS Electricity Market Module (EMM) solely to help determine electricity prices. Unlike the other RFM technology characterizations, the MSW-to-energy facility characterization is not used to compete MSW energy against other energy sources. This modeling treatment stems from the assumption that MSW energy, as a byproduct of the waste removal process, is fully utilized as it is produced.

Several sources for the cost and performance characterization data were examined for use in the RFM. Among these were the technology characterizations developed by the DOE Office of Energy Efficiency and Renewable Energy (EE), data inputs to the DOE Policy Office's Integrated Dynamic Energy Analysis Simulation (IDEAS) model, and the Electric Power Research Institute's 1993 *Technical Assessment Guide* (EPRI TAG). The IDEAS data are older, and are not consistent with some RFM variable categories. The EPRI TAG data was chosen as the most credible and consistent data for most technologies; however, in some cases EE data were used.

The sources provide values for capital costs (excluding the construction financing and contingency components, since these are provided in the EMM), fixed and variable operation & maintenance (O&M) costs, capacity factors for solar electric technologies, and construction lead times. All cost values are converted to real 1987 dollars.

All information passed from the RFM to other NEMS modules are placed in a COMMON block called /WRENEW/. (A COMMON block is a FORTRAN data area located outside of the NEMS analytical modules). It should be noted that no data are passed among the RFM submodules; that is, there are no variables written into COMMON /WRENEW/ by an RFM submodule that are subsequently read by any of the other RFM submodules.

Provided below are summaries of the six RFM submodules that are used for producing the AEO95 forecasts: the Municipal Solid Waste Submodule (MSW), the Wind Energy Submodule (WES), the Solar Energy Submodule (SOLES), the Biofuels Supply Submodule (BSS), the Wood Submodule, and the Geothermal Electricity Submodule (GES). The RFM's role in providing the EMM with hydropower data are also described. The chapter concludes with information on the RFM archival package and EIA point of contact.

Municipal Solid Waste Submodule (MSW)

The Municipal Solid Waste Submodule provides annual projections of energy produced from the incineration of municipal solid waste (MSW). The Submodule uses the quantity of MSW produced (derived from an econometric equation that uses Gross Domestic Product as the principal forecast driver), the heating value of a pound of MSW, and shares of MSW combusted for energy recovery. The energy production forecasts are disaggregated by consuming sector (commercial, industrial, and utility). In addition, the MSW Submodule supplies the utility sector (EMM) with capital and operating cost information. This cost information is only used by the EMM to calculate electricity prices; MSW-produced power is viewed as a byproduct of a community's waste disposal activities and only secondarily as a competitive alternative to other fuels for energy production.

Wind Energy Submodule (WES)

The Wind Energy Submodule (WES) projects the availability of wind resources as well as the cost and performance of wind turbine generators. This information is passed to the EMM so that wind turbines can be built and dispatched in competition with other electricity generating technologies. The wind turbine data are expressed in the form of energy supply curves. The supply curves provide the maximum amount of turbine generating capacity that could be installed, given the available land area, average wind speed, and capacity factor. These variables are passed to EMM in the form of nine time slices which are matched to electricity load curves within EMM.[2]

Solar Submodule (SOLES)

The solar submodule projects the cost and performance characteristics of photovoltaic (PV) and solar thermal central station electric installations. (The submodule considers only grid-connected applications constructed by a utility or independent power producer.) This information is passed to the EMM for building and dispatching these solar technologies in competition with other electricity generation technologies.

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[2] The nine time slices are derived from three 8-hour segments of the day for three seasons—winter, summer and off-peak (spring/fall averaged). The data represent average capacities based on empirical analysis.

The required input information is similar for each type. Capacity projections are developed as endogenous inputs to be competed against other generating technologies (i.e., costs, capacity factors, and fixed and variable O&M costs). Solar is a renewable energy form that requires a more detailed characterization to represent its intermittent nature and regionality. This is dealt with by the regional load shapes used by the EMM and different time slices to represent intermittency (for example, that there is no sunlight at night). Little if any solar capacity is being built currently because of the high cost.

Biofuels Supply Submodule (BSS)

This submodule produces annual supply functions (cost vs. quantity) by Petroleum Allocation for Defense Districts (PADD) and by Census division for corn-derived ethanol. The agricultural feedstock production quantities and costs are provided exogenously to NEMS from a U.S. Department of Agriculture linear programming model, Agricultural Resources Interregional Modeling System (ARIMS). The supply curves take into account feedstock costs, feedstock conversion costs, and energy prices. The supply functions are used by the Petroleum Market Module to compute regional demands for ethanol.

Wood Submodule

The Wood Submodule furnishes cost and performance characteristics for a wood burning electricity generating technology to the EMM. The technology modeled for the AEO95 is the Integrated Gasification Combined Cycle (IGCC). The submodule utilizes a regional wood supply schedule from which the wood fuel price is determined; fuel prices are added to variable operating costs since there are no fuel costs in the structure of NEMS for renewable fuels. The wood supply schedule is based on the accessibility of wood resources by the consuming sectors from existing timber and wood residues. For the AEO95 energy crops are not included. There are plans for their inclusion in AEO96.

Geothermal Electricity Submodule (GES)

The purpose of the GES is to model current and future regional supply, capital cost, and operation and maintenance costs of electric generating facilities using hydrothermal resources (hot water and steam). These resources are limited to three EMM regions in the western United States (11, 12 and 13). The data are assembled from specific site information which reflects the conditions of that location. Capital and operating costs can vary among sites. For AEO95 a non-integrated version of the GES was used which relied on the data structure within the GES to produce supply schedules which corresponded to levelized costs of $.05/kWh or less. These costs parameters were then entered into the appropriate areas of the RFM for inclusion in EMM capacity expansion decisions. The components of GES that were required for AEO95 are documented in chapter 7.

Hydroelectric Plant Data

The EMM uses currently available and planned regional hydropower capacity and capacity factors for modeling conventional hydroelectric facility utilization. This plant information is derived by processing and aggregating the responses of utility and nonutility power producers to annual EIA power plant surveys (Forms EIA-860, EIA-759, and EIA-867). Prior to calling the renewable energy submodules, the RFM reads the capacity and capacity factor values from the EMM plant file into the WRENEW COMMON block variables (hydroelectric capacity, WCAHYEL, and capacity factor, WCFHYEL). These COMMON block variables are subsequently used by the EMM Electricity Fuel Dispatch (EFD) and Electricity Capacity Planning (ECP) submodules.

In addition to capacity and capacity utilization inputs, the EMM also requires capital costs and fixed and variable operation & maintenance costs for the calculation of electricity prices in the Electricity Finance and Pricing (EFP) submodule. These inputs, which come from the EPRI TAG, are contained in an input table named TECHP, located in the RFM source code. Table TECHP has the following hydroelectric plant parameters which pertain to the EPRI West region: Capital Cost—$1,849 per kilowatt; Fixed Operating Cost—$10.2 per kilowatt; Variable Operating Cost—3.2 mills per kilowatthour.

These EPRI regional values need to be converted into NEMS Electricity Supply (NERC) regions. The model accomplishes this conversion in three steps. In step one, a set of six EPRI TAG regional cost adjustment factors are mapped to NERC regions with the use of a mapping array, MAPEN. The regional cost adjustment factors, located in the RFM source code as table TECHF, are as shown in Table 1:

Table 1. EPRI Regional Cost Adjustment Factors

EPRI Region	Cost Adjustment Factor
Northeast	1.09
Southeast	0.95
East Central	1.00
West Central	1.00
South Central	0.98
West	1.05

In the NERC numbering system, this corresponds to the values in Table 2:

Table 2. NERC Regional Cost Adjustment Factors

NERC Region	Cost Adjustment Factor
1	1.00
2	0.98
3	1.09
4	1.00
5	1.00
6	1.09
7	1.09
8	0.95
9	0.95
10	0.98
11	1.05
12	1.05
13	1.05

In step two, the 13 cost adjustment factors are divided by the cost adjustment factor for the EPRI West region, where the EPRI TAG prototype hydroelectric plant was located.

Finally, these normalized cost adjustment ratios are multiplied by the elements in TECHP to obtain the regionalized EPRI TAG plant cost parameters.

Hydropower modeling in NEMS focuses only on planned hydroelectric capacity additions and reductions through the year 2001 (the end point of the 1991 EIA-860 survey 10-year planning horizon). Unplanned capacity changes beyond 2001 are assumed to offset one another, resulting in no net change in hydroelectric capacity for the duration of the forecast horizon. Since hydropower O&M costs are assumed to be the lowest of any major generating technology, and hydropower produces virtually no air pollution, all available hydro capacity is used first by the EMM.

Archival Media

The RFM is archived as part of the National Energy Modeling System production runs.

Model Contact

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Report Organization

Subsequent chapters of this report provide detailed documentation of each of the RFM's six working submodules. Each chapter contains the following sections:

- Model Purpose—a summarization of the submodule's objectives, detailing input and output quantities, and the relationship of the submodule to other NEMS modules

- Model Rationale—a discussion of the submodule's design rationale, including insights into assumptions utilized in the model development process, and alternative modeling methodologies considered during submodule development phase

- Model Structure—an outline of the model structure, using text and graphics to illustrate the major model data flows and key computations

- Appendices—supporting documentation for input data and parameter files currently residing on the EIA mainframe computer. Appendix A in each RFM submodule chapter lists and defines the input data used to generate parameters and endogenous forecasts. Appendix B contains a mathematical description of the computation algorithms, including model equations and variable transformations. Appendix C is a bibliography of reference materials used in the model development process. Appendix D consists of a model abstract. Appendix E discusses data quality and estimation methods.

2. Municipal Solid Waste (MSW) Submodule

Model Purpose

The main purpose of the Municipal Solid Waste (MSW) Submodule is to provide NEMS with annual projections of energy produced from the incineration of municipal solid waste (MSW). The submodule uses the quantity of MSW produced, the heating value of MSW, and shares of MSW combusted for energy recovery to produce forecasts of the production of electricity and other energy forms. The energy production forecasts are disaggregated by consuming sector (commercial, industrial, and electric utility) and region.

In addition to energy production forecasts, the MSW Submodule supplies NEMS with waste-to-energy (WTE) facility capital and operating costs. For policy analysis, the Submodule contains a policy variable that models the effects of MSW source reduction efforts.

Relationship of the MSW Submodule to Other Models

Unlike most of the submodules of the Renewable Fuels Module, the MSW Submodule does not provide other NEMS modules with information used to allow the renewable energy resource to compete with alternative energy forms. Rather, forecasted MSW energy production is used to reduce the energy demand that is modeled in the NEMS end-use demand and utility modules (i.e., MSW energy is decremented from each sectoral energy requirement; in the case of the electric utility sector, generating capacity is decremented). This treatment of MSW energy production in NEMS stems from MSW energy being viewed primarily as a byproduct of a community's waste disposal activities rather than a competitive alternative to other fuels.

The only input from other NEMS modules is annual real Gross Domestic Product (GDP), which comes from the NEMS Macroeconomic Activity Module (MAM) variable COMMON block (variable name MC_GDP).

The outputs to the NEMS commercial, industrial, and electric utility modules include the following:

- Quantities of total energy produced annually by WTE facilities for each region and end-use sector. For the NEMS industrial and commercial sector modules, energy forecasts are provided in thermal units (million Btu) by Census division. For the Electricity Market Module (EMM), energy forecasts are converted to megawatt-electric equivalents and reported by NERC region.

- Capital cost (plant and startup costs, plus interest during construction), variable operating cost, and fixed operating cost for WTE facilities, to be used by the EMM for calculating purchased electricity costs.

Modeling Rationale

Theoretical Approach

The modeling methodology employs a simple linear MSW supply function and multiplicative energy allocation shares for deriving disaggregated MSW energy production forecasts. The methodology consists of four major steps. First, the total quantity of MSW in the United States is projected using univariate regression estimation to derive parameters for the MSW supply equation (an add factor representing the impact of MSW source reduction is also included in the equation). Second, the current and future heat value of a typical pound of MSW is assessed for estimating the potential quantity of energy that can be produced from combusting MSW. Third, estimates of the total U.S. capacity to burn MSW with heat recovery are obtained using analyst judgement of factors affecting community approval and investments in WTE facilities. Fourth, regional and sectoral projections of energy from MSW combustion are obtained by multiplying together MSW quantities, Btu heating values, percentages of MSW combusted, and sectoral/regional energy allocation shares.

While this approach is essentially unchanged from the methodology used for previous AEO forecasts, there are some new features that have been incorporated into the NEMS version. First, the MSW supply forecasting equation, which is based on GDP, will access that variable directly from the NEMS Macroeconomic Activity Module and thus be consistent with economic assumptions used throughout NEMS. Previously, MSW supply projections were based on off-line forecasts of economic growth. Second, MSW energy projections will make the transition from the ten Federal regions utilized in the AEO Forecasting System to NEMS regions (Census Divisions and NERC regions). Third, the flexibility with which important input variables can be changed, such as the assumed percentage of MSW that is combusted, has been improved.

Because of the byproduct nature of MSW energy, the relatively small quantity of MSW in the U.S. energy mix, and the complexity of modeling the municipal WTE market, a simple modeling approach that excludes the consideration of energy demand, price, and technology investment signals from other NEMS modules was selected. One of the major limitations of this approach is that there are no economic or financial links for determining key parameters, especially the share of MSW combusted and the regional distribution of WTE energy capacity.

Fundamental Assumptions

MSW Quantity Projections

The definition of MSW adopted for the MSW Submodule is consistent with that used by the Environmental Protection Agency (EPA) and defined in Subtitle D of the Resource Conservation and Recovery Act. Municipal solid waste includes discarded durable goods, nondurable goods, containers and packaging, food wastes, and yard trimmings from the residential, commercial, institutional, and industrial sectors. MSW does not include everything that might be landfilled in Subtitle D landfills, such as municipal sludge, nonhazardous industrial wastes, shredder residue from automobile recycling operations, and construction and demolition wastes. These wastes are often disposed alongside those wastes formally defined as MSW. The MSW Submodule does not currently represent energy that may be generated from the combustion of Subtitle D wastes other than MSW. However, it is possible that some existing capacity could be used for combustion of these additional Subtitle D wastes.

Projected Btu Value of MSW

The Btu value of a typical pound of MSW is changing rapidly in response to changes in the usage and disposal of specific materials. Curlee (1992) provides information on the historical and projected composition of MSW in terms of the waste stream's material composition. In this estimate, the Btu value of one pound of MSW has increased from about 3,800 Btu in 1960 to about 5,100 Btu in 1990.

There are numerous factors that influence the Btu value of combusted MSW. For example, marketing efforts have been responsible for the gradual replacement of glass and some metal with plastic, especially for containers. Partially counteracting these marketing efforts are restrictions that have been successfully implemented in some States to limit the usage of plastics in selected packaging. Many communities require that yard waste (which has a low energy content) to be collected separately from other wastes and composted rather than burned or landfilled. Other communities simply restrict households from disposing of their yard waste along with other MSW. The number of curbside recycling programs is increasing, and most collect and recycle both plastics and paper (the highest Btu components of the waste stream), and glass and metals (which have no energy value).

Combining EPA projections of this changing MSW mix with the heat content of waste components, Curlee projects a total heat content for MSW of 5,569 Btu per pound of waste in the year 2000. It was assumed by EIA that, post-2000, the heat content would remain constant at the 5,569-Btu level, based on the expectation that the removal of low-Btu waste stream components (metal, glass, and yard waste) will be balanced by the removal of high-Btu components (paper and plastic). While these changes in MSW composition are significant, it is not believed that the relationship of GDP to tons generated will be affected by such changes.

Projected Percentage of MSW Combusted With Heat Recovery

Projections of WTE market penetration, and therefore the share of generated municipal waste combusted, are difficult to make. Projections for the near term—i.e., the next 5 years—can be based on existing data on WTE projects in the planning and construction phases. Consideration should be given to expected unit cancellations, which have occurred more frequently in recent years. The methodology adopted for the MSW Submodule beyond 1995 requires the use of assumed fractions of MSW supplies combusted for energy recovery. The procedure used to derive these combusted-fraction values is described in Appendix 2E, page 25.

Disaggregation Rules

National projections for energy from MSW are disaggregated into regional totals according to the geographical dispersion of current and planned WTE facilities, use of the MSW energy (electricity versus steam and heat), and sector (commercial, industrial, and utility). Information used for disaggregating MSW energy comes from the Government Advisory Associates (GAA) Resource Recovery Database. This proprietary database product includes information on locations, types of energy produced, ownership type, etc. for all existing U.S. WTE facilities, as well as those facilities in the construction, conceptual-planning, and advanced-planning stages.

For 1990 to 1996, the regional, usage, and sectoral totals are computed using GAA's site-level facility data. The Btu capacities of WTE facilities that are expected to come on-line before 1996 are assigned to the appropriate NEMS regions. Specifically, MSW electricity production for sales are disaggregated by NERC regions, and energy derived for heat and steam are disaggregated by Census divisions.

Given that no data currently exist to indicate how these breakdowns may change beyond 1996, it is assumed that the percentage of total WTE capacity allocated to region, use, and sector remains constant after 1996. Additional research into regional characteristics that could influence the shares, such as land values or recycling markets, may result in an improved approach for disaggregation of national totals.

Capital and Operating Costs

The MSW submodule supplies the EMM with capital and operating costs to help in the determination of electricity prices. In lieu of actual cost data from WTE facilities, the MSW Submodule employs technology cost characterization information from the EPRI 1989 Technical Assessment Guide (TAG). Information for the mass burn technology is selected because this technology is the most common of three technology types.[3] For both capital and operating costs, the TAG assumes a WTE plant size of 40 megawatts with a single combustion unit. Additional information on the EPRI TAG cost values is provided in Appendix 2A.

An important component of the WTE facility operating cost is the tipping fee. The tipping fee is a per-ton charge assessed to waste removal firms for depositing the MSW at the disposal site. Because the tipping fee is a revenue source, the MSW Submodule treats the tipping fee as a negative fuel cost.

At this time there are insufficient data on how tipping fees are determined, although it is likely that they are the balancing factor in plant economics. A complication with tipping fees is that

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[3]Mass burn WTE units combust MSW without preprocessing, other than the removal of large items from the feed system. Refuse Derived Fuel (RDF) facilities combust waste that has been preprocessed (i.e., sorted and shredded to increase the heating value). A third technology type—modular combustors—are small, prefabricated units. Mass burn units constitute 39 percent of operating WTE units and 79 percent of planned WTE units.

some plants are privately owned, others are publicly owned, and subsidies may be involved in either case. As a result, tipping fee values are currently assumed to remain constant for all forecast years.

Alternative Approaches

Only two other sources of energy projections from MSW combustion have been identified -- the Solar Energy Research Institute (SERI, 1990) and Klass (1990). The projections from those reports are discussed in Curlee (1991). MSW energy projections given in Curlee (1991), which are based on the methodology adopted for the MSW Submodule, are significantly higher than those contained in the reports by SERI and Klass. Note that MSW is one of several renewable energy sources evaluated in both the Klass and SERI studies, and the underlying assumptions and modeling methodologies are not explained sufficiently in either study to discuss and compare the differences between their approaches and the MSW Submodule approach. No other models of MSW energy consumption and production were identified in the research supporting the development of the MSW Submodule.

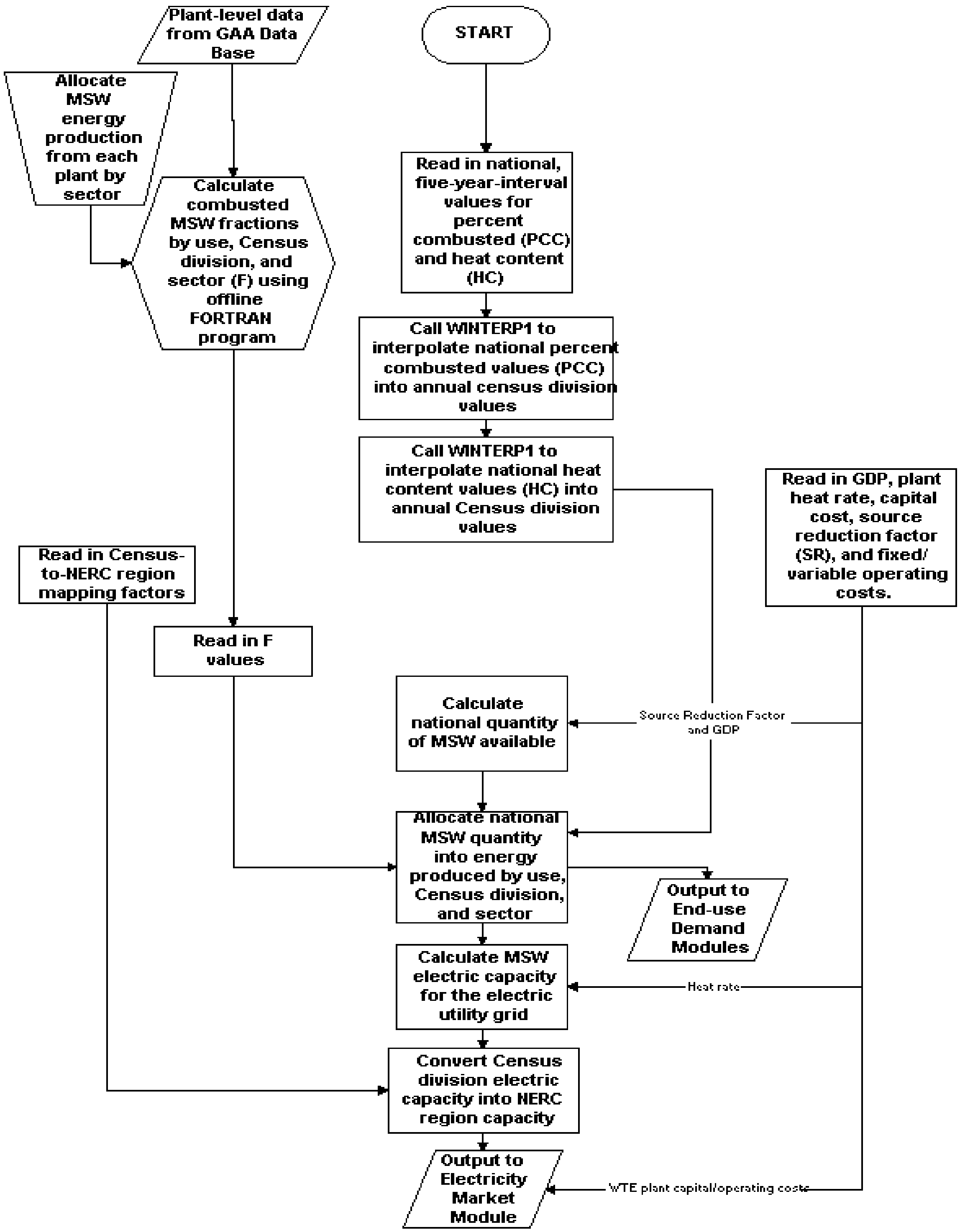
A key aspect of the selected modeling approach involves the application of expert judgement for specifying the projected regional fractions of MSW combusted for energy. (These fractions are multiplied by available MSW in order to determine the projected MSW quantities available for energy recovery.) Ideally, judgements concerning projected combustion fractions should be combined with an analysis of cost and capacity trends involving the reduction, recycling, composting, landfilling, processing, and combusting of MSW. However, relative cost information for the various alternatives to manage MSW is currently considered inadequate, and is therefore not used.

MSW Submodule Structure

Submodule Flow Diagram

This section presents a flow diagram of the MSW Submodule that shows the Submodule's main computational steps and data relationships.

Figure 1. Municipal Solid Waste Submodule Flowchart



Key Computations and Equations

The MSW Submodule first computes the annual amount of MSW, in a direct linear relationship with economic activity as represented by GDP, and adjusted for efforts to reduce MSW. The quantity, in million tons, that is generated nationally is:

$$QNAT = \alpha + \beta \ x \ MC\_GDP_T \ x \left[1 - (T - 1) \ x \ SR\right] \tag{2-1}$$

where:

$QNAT$	=	Quantity of municipal solid waste generated in the United States, this variable is for internal use only and is overwritten on each iteration,
α	=	an econometrically estimated parameter equal to 14.60,
β	=	an econometrically estimated parameter equal to 0.03599,
T	=	current NEMS year,
MC_GDP_T	=	real gross domestic product for year T, and,
SR	=	annual source reduction factor.

Additional detail on the estimation of α, β and SR is given in Appendix 2-B. The next step is to compute the amount of energy obtained from the national MSW supply quantity, and disaggregate the energy into usage, regional, and sectoral shares.[4] The following equation determines the quantity shares of energy, measured in millions of Btu per year, that is produced from MSW:

$$Q_{U,RC,S} = QNAT \ x \ PCC_{RC,T} \ x \ HC_{RC,T} \ x \ F_{U,RC,S} \ x \ 2000 \tag{2-2}$$

where:

$Q_{U,RC,S}$	=	quantity of energy produced from municipal solid waste for use U (where U_1= electricity supplied to the grid, U_2 = electricity supplied for own use, and

[4]All energy produced from MSW is assumed to be used by the three consuming sectors.

		U_3 = steam and other), sector S (where S_1 = commercial sector, S_2 = industrial sector, and S_3 = electric utility sector), in Census division *RC*,
QNAT	=	quantity of municipal solid waste generated in the United States,
$PCC_{RC,T}$	=	percent combusted for Census division *RC* in year *T*,
$HC_{RC,T}$	=	heat content for Census division *RC* in year *T*, and
$F_{U,RC,S}$	=	fraction of MSW combusted for use *U* in sector *S* in Census division *RC*.

The production capacity for all energy forms (electricity and other) is then combined into a total energy production capacity for the commercial and industrial sectors. The annual electric capacity available for MSW facility own-use and sale to the electric utility grid is calculated using the following equation:

$$WCAMSELRC_{RC,T} = \frac{\left[\sum_{U=1}^{2} Q_{U,RC,S=3}\right] x\ 10^6}{HR1\ x\ 8760\ x\ 1000} \quad \textbf{(2-3)}$$

where:

$WCAMSELRC_{RC,T}$	=	Annual MSW electric capacity in megawatts for own-use and sale to the utility grid in Census division *RC* in year *T*,
HR1	=	Heat rate for MSW (Btu in/kWh out), and,
$Q_{U,RC,S=3}$	=	Annual electricity production from MSW in millions of Btu for both sale to the grid (U=1) and own-use (U=2), in the electric utility sector (S=3), in Census division *RC*.

Finally, the annual electricity production is mapped from Census divisions to NERC regions using a mapping matrix.

Appendix 2-A: Inventory of Variables, Data, and Parameters

This Appendix describes the variables, parameter estimates, and data inputs associated with the MSW Submodule. Table 2A-1 provides a tabular listing of model variables, input data, and parameters. The table contains columns with information on item definitions, modeling dimensions, data sources, measurement units, and documentation page references.

The remainder of Appendix 2A consists of detailed descriptions of data inputs and variables, including discussions on supporting data assumptions and transformations.

Table 2A-1. NEMS Municipal Solid Waste Submodule Inputs and Outputs

Model Variable	Definition and Dimensions	Source	Units	Page Reference
INPUT DATA				
F	Fraction of MSW combusted for use *U* and sector *S* in Census division *RC*	Government Advisory Associates. processed using off-line Fortran program	Unitless	20, 24, 34, 59, 62
HC	MSW heat content values in Census division *RC* in year *T*	Franklin Associates and Office of Technology Assessment	Btu/lb of MSW	16, 22, 30
HR1	MSW heat rate for electricity production	Government Advisory Associates	Btu in/ kWh out	16, 23, 31
MPCRNR	Conversion factors for converting Census division *RC* to NERC Region *RN*	Government Advisory Associates	Unitless	20, 23, 32
PCC	Percent combusted for Census division *RC* in year *T*	Franklin Associates and EIA staff	Percentage (converted to a factor by dividing by 100)	16, 24, 30, 66
RCAPFEL	Capacity factor of a WTE plant	EPRI TAG	Unitless	25
RCAP	Capital cost for a WTE plant	EPRI TAG	$/KW	26
RNCFUEL	Tipping fee for MSW in Census division *RC*	Chupka, et al	$/ton	26
RCOM	Fixed O&M cost for a WTE plant	EPRI TAG	mills/kWh	27
RVOM	Variable O&M cost for a WTE plant	EPRI TAG	mills/kWh	27, 37
SR	Annual source reduction factor	Oak Ridge National Lab	Percentage	15, 28, 29, 62
CALCULATED VARIABLES		NA*		
MC_GDP	Real gross domestic product for year *T*		Billion $	15, 29
Q	Quantity of energy from municipal solid waste for use *U* and sector *S* in Census Division *RC*		MMBtu per year	15, 16, 30, 31
QNAT	Quantity of municipal solid waste produced in the U.S.		million tons per year	15, 16, 29, 30

Table 2A-1. NEMS Municipal Solid Waste Submodule Inputs and Outputs (Continued)

Model Variable	Definition and Dimensions	Source	Units	Page Reference
WCAMSEL	MSW electric capacity for utilities in NERC Region *RN* in year *T*		Megawatts	32
WCAMSELRC	MSW electric capacity for utilities in Census division *RC* in year *T*		Megawatts	16, 31, 32
WCAMSCM	MSW thermal capacity for the commercial sector in Census division *RC* in year *T*		MMBtu/yr	30
WCAMSIN	MSW thermal capacity for the industrial sector in Census division *RC* in year *T*		MMBtu/yr	31
WCCMSEL	Capital cost of MSW electric generating capacity in NERC Region *RN* in year *T*		$/kW	26
WCFMSEL	Capacity factor for utilities in NERC Region *RN* in year *T*		Unitless	26
WFCMSEL	Fuel cost of MSW electric generating capacity in NERC Region *RN* in year *T*		$/ton	26, 32, 33
WFCMSELM	Fuel cost of MSW electric generating capacity in mills/kWh for NERC Region *RN* in year *T*		mills/kWh	32, 33
WHCMSEL	Heat content for utilities in NERC Region *RN* in year *T*		Btu/lb of MSW	32
WHRMSEL	Heat rate for utilities in NERC Region *RN* in year *T*		Btu in/ kWh out	36
WOCMSEL	Fixed O&M cost of MSW electric generating capacity in NERC Region *RN* in year *T*		mills/kWh	27
WVCMSEL	Variable O&M cost of MSW electric generating capacity in NERC Region *RN* in year *T*		mills/kWh	27, 37
PARAMETERS				
α, β	Econometrically estimated parameters	Obtained from regressing historical MSW generation on Gross National Product	Unitless	19, 33, 65

*NA = Not applicable for calculated values.

MODEL INPUT: $F_{U,RC,S}$

DEFINITION: Fraction of total MSW generated that is combusted for use *U* in sector *S* in Census Division *RC*

Once the total amount of MSW that is combusted for energy has been determined, it must be allocated among uses (electricity or other), regions (Census divisions and NERC Regions), and sectors (commercial, industrial, and utility) (Table 2A-2). The allocation factor matrix *F* accomplishes this task by using historical and 1995 projected plant level data from the Governmental Advisory Associates (GAA) 1991 Resource Recovery Database. These data were processed with an off-line FORTRAN program that determines the values for *F*, along with the heat rate, *HR1*, and the Census-to-NERC regional mapping factors, *MPCRNR*. (The FORTRAN program and the process used to derive input values for *F*, *HR1*, and *MPCRNR* are described in Appendix 2E.) The *F* matrix used as Submodule input is provided below.

SOURCES: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 13-14.

Government Advisory Associates, *Resource Recovery Yearbook* and 1991 Resource Recovery Database, 177 East 87th Street, New York, NY, 1991.

Table 2A-2. NEMS Municipal Solid Waste Combustion Fractions

	Electricity to the grid (U = 1)	Electricity for own use (U = 2)	Electricity for steam (U = 3)
Commercial Sector (S = 1)			
1	.000000	.000000	.001863
2	.000000	.000000	.005320
3	.124753	.022944	.000000
4	.000000	.000000	.029335
5	.000093	.000103	.006751
6	.232555	.044410	.000000
7	.000987	.004572	.017175
8	.000000	.000000	.015477
9	.065522	.014119	.000000
Industrial Sector (S = 2)			
1	.000000	.000000	.002011
2	.000000	.000000	.009857
3	.028898	.005112	.000000
4	.000000	.000000	.012777
5	.005286	.000753	.033947
6	.166205	.025733	.000000
7	.000000	.000000	.001103
8	.000000	.000000	.011644
9	.004144	.003849	.000000
Utility Sector (S = 3)			
1	.000000	.000000	.000299
2	.000000	.000000	.002244
3	.009209	.004295	.000000
4	.000000	.000000	.001955
5	.000000	.000000	.004839
6	.003451	.000863	.000000
7	.000000	.000000	.003307
8	.000000	.000000	.002091
9	.059124	.011032	.000000

MODEL INPUT: *HC*

DEFINITION: Heat content for Census division *RC* in year *T*

Heat content values, measured in Btu per pound of MSW, are available in five year intervals from 1990 through 2015. The HC values are provided in Table 2A-3 below.

Table 2A-3. Heat Content of MSW

Year	Heat Content, *HC* (Btu per pound of MSW)
1990	5,114
1995	5,333
2000	5,569
2005	5,569
2010	5,569

Intermediate annual values are obtained by an interpolation subroutine named WINTERP1. Heat contents are national data, and are assumed to be the same for each Census division. The historic and projected percent composition of MSW was obtained from Franklin Associates for each of the main components of MSW. The main components of MSW include: paper and paper board, glass, metals, plastics, rubber and leather, textiles, wood, food waste, yard waste, other organics, and other inorganics. The Btu content was obtained for each material from the Office of Technology Assessment. The percentages and Btu contents were combined to provide an overall heat content per pound of MSW. Values for the years through 2000 were based on an assumed continuation of the historical increasing trend. Beyond 2000, it was assumed that HC remains level for the duration of the forecast horizon.

SOURCES: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 7-10.

Franklin Associates, "Characterization of Municipal Solid Waste in the United States: 1992 Update Final Report," prepared for the Environmental Protection Agency, Municipal and Industrial Solid Waste Division, Office of Solid Waste, July 1992.

Curlee, T. Randall, "Projections of Energy from the Combustion of Municipal Solid Waste: 1993 DOE-AEO Update, Draft Report," prepared for EIA, July 1992.

Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?*, Congress of the United States, U.S. Government Printing Office, Washington, DC, October 1989.

<u>MODEL INPUT</u>: *HR1*

<u>DEFINITION</u>: Heat rate for MSW energy conversion

The heat rate, set at 16,283.9 Btu per kilowatthour, is assumed constant for all NERC Regions, sectors, and years. The heat rate is calculated using Governmental Advisory Associates data and an off-line FORTRAN program. For those plants that cogenerate electricity and steam, the heat rate is assumed to equal the heat rate of facilities that generate only electricity.

<u>SOURCES</u>: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 15.

Government Advisory Associates, *Resource Recovery Yearbook*, 177 East 87th Street, New York, NY, 1991.

<u>MODEL INPUT</u>: *MPCRNR*

<u>DEFINITION</u>: Matrix of factors for converting Census division *RC* to NERC Region *RN*

The data used to develop conversion factors were obtained from the Government Advisory Associates (GAA) 1991 Resource Recovery Database. These conversion factors were calculated from the same FORTRAN program used to develop the *F* matrix. The GAA data file includes WTE capacity for facilities that are expected to come on-line between 1990 and 1995. The matrix is provided in Table 2A-4.

<u>SOURCES</u>: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 15.

Government Advisory Associates, *Resource Recovery Yearbook* and Resource Recovery Database, 177 East 87th Street, New York, NY, 1991.

Table 2A-4. Census Division to NERC Region Conversion Factors

	Census Divisions								
NERC Region	1	2	3	4	5	6	7	8	9
1	.0000	.0466	.6734	.0000	.1294	.0000	.0000	.0000	.0000
2	.0000	.0000	.0000	.0000	.0000	.0000	.0311	.0000	.0000
3	.0000	.6003	.0000	.0000	.1615	.0000	.0000	.0000	.0000
4	.0000	.0000	.3197	.0000	.0000	.0000	.0000	.0000	.0000
5	.0092	.0000	.0069	1.0000	.0000	.0000	.0000	.0000	.0000
6	.0000	.3530	.0000	.0000	.0000	.0000	.0000	.0000	.0000
7	.9908	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
8	.0000	.0000	.0000	.0000	.6072	.0000	.0000	.0000	.0000
9	.0000	.0000	.0000	.0000	.1018	1.0000	.0000	.0000	.0000
10	.0000	.0000	.0000	.0000	.0000	.0000	.9689	.0000	.0000
11	.0000	.0000	.0000	.0000	.0000	.0000	.0000	1.0000	.4088
12	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
13	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.5912

MODEL INPUT: *PCC*

DEFINITION: Percent MSW combusted for Census division *RC* in year *T*

National percent combusted values, available in 5-year intervals, are presented in Table 2A-5.

These percentage values are divided by 100 to produce factors. The MSW Submodule then calculates intermediate annual values using an interpolation subroutine named WINTERP1. Finally, the PCC factors are read into a regional PCC matrix, thereby yielding *PCC* values that are constant across all Census divisions.

Estimates of percent of MSW combusted for 1960 through 1990 were obtained from Franklin Associates. Data for the years after 1990 are projections based on analyses conducted by the Oak Ridge National Laboratory and EIA staff.

Table 2A-5. Percent MSW Combusted

Year	Percent MSW Combusted, *PCC*
1990	15.2
1995	20.0
2000	25.0
2005	28.0
2010	30.0

<u>SOURCES</u>: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 12.

Franklin Associates, "Characterization of Municipal Solid Waste in the United States: 1992 Update Final Report," prepared for the Environmental Protection Agency, Municipal and Industrial Solid Waste Division, Office of Solid Waste, July 1992.

Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?*, Congress of the United States, U.S. Government Printing Office, Washington, DC, October 1989.

Curlee, T. Randall, "MSW Projections for the EIA 1992 Annual Energy Outlook, Draft Report," prepared for EIA, August 1991.

<u>MODEL INPUT</u>: *RCAPFEL*

<u>DEFINITION</u>: Capacity factor for a Waste-to-Energy (WTE) plant

The capacity factor is obtained from the EPRI *Technical Assessment Guide* (TAG). It is assumed to be 0.85 for all regions and years. The MSW submodule assigns this capacity factor value to the RFM common block variable, WCFMSEL.

<u>SOURCES</u>: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 19.

Electric Power Research Institute, *TAG Technical Assessment Guide.* EPRI P-6587-L, Vol. 1: Rev. 6, Palo Alto, CA, 1989.

MODEL INPUT: *RCAP*

DEFINITION: Capital cost of a WTE plant

The unadjusted capital cost, $4,630 per kilowatt, is obtained from the EPRI *Technical Assessment Guide* (TAG). The TAG capital cost is expressed in December 1988 dollars, and is converted to 1987 dollars by multiplying the cost by the ratio of the Implicit GNP Price Deflator value midway between the 1988 and 1989 values, and the 1987 Deflator value. The adjusted capital cost value used as model input is $4,389 per kilowatt. The MSW submodule assigns this capital cost value to the RFM common block variable, *WCCMSEL*.

SOURCES: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 19.

Electric Power Research Institute, *TAG Technical Assessment Guide.* EPRI P-6587-L, Vol. 1: Rev. 6, Palo Alto, CA, 1989.

MODEL INPUT: *RNCFUEL*

DEFINITION: Tipping fee charged for MSW

The tipping fee is structured as a negative adjustment to the fuel cost variable, *WFCMSEL*. Tipping fees were calculated based on data from Chupka, Howarth, and Zoi. The tipping fees, originally expressed in dollars per ton of MSW, are aggregated to Census Regions using MSW facility consumption weighting factors, converted to real 1987 dollars, and then transformed into mills-per-kilowatthour.

SOURCES: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 18.

Chupka, Marc, D. Howarth, and C. Zoi. *Renewable Electric Generation: An Assessment of Air Pollution Prevention Potential*. EPA/400/R-92/005, U.S. Environmental Protection Agency, 1992.

MODEL INPUT: *RCOM*

DEFINITION: Fixed operation & maintenance (O&M) cost for a WTE plant

Data for calculating operating costs are obtained from the EPRI Technical Assessment Guide (TAG). Data are available for mass burn technology and refuse derived fuel. Information for the mass burn technology is used in the calculations. Fixed operating and maintenance costs are listed as $118.6 per kilowatt per year. At an 85 percent capacity factor, this equals $0.0159 per kWh in December 1988 dollars. To convert from December 1988 dollars to 1987 dollars, the O&M cost is multiplied by the ratio of the Implicit GNP Price Deflator value midway between the 1988 and 1989 values, and the 1987 Deflator value. Therefore, in real 1987 dollars, the fixed O&M cost is $0.0151 per kWh, or 15.1 mills per kWh. The MSW submodule assigns this O&M cost value to the RFM common block variable, *WOCMSEL*.

SOURCES: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 19.

Electric Power Research Institute, *TAG Technical Assessment Guide.* EPRI P-6587-L, Vol. 1: Rev. 6, Palo Alto, CA, 1989.

MODEL INPUT: *RVOM*

DEFINITION: Variable O&M cost for a WTE plant

Data for calculating the operating cost are obtained from the EPRI Technical Assessment Guide (TAG). Data are available for mass burn technology and refuse derived fuel. Information for the mass burn technology is used in the calculations. Variable operating costs are listed as 0.0181 $/kWh in 1988 dollars. To convert from December 1988 dollars to 1987 dollars, the O&M cost is multiplied by the ratio of the Implicit GNP Price Deflator value midway between the 1988 and 1989 values, and the 1987 Deflator value. Therefore, in real 1987 dollars, the variable O&M cost is 0.0173 $/kWh, or 17.3 mills per kWh. Finally, the variable operating cost is adjusted by subtracting the tipping fee, and assigning the operating cost value to the RFM common block variable, *WVCMSEL*.

SOURCE: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 19.

MODEL INPUT: *SR*

DEFINITION: Annual source reduction factor

The annual source reduction factor, based on expert judgement from Oak Ridge National Laboratory is 0.5 percent per year, or 0.005. For additional details on the derivation of *SR*, see Appendix 2E.

SOURCES: Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 6.

Appendix 2-B: Mathematical Description

This Appendix provides the detailed mathematical specification of the MSW Submodule as presented in the RFM FORTRAN code execution sequence. Subscript definitions are also as they appear in the FORTRAN code.

The generation of MSW is postulated to be primarily a function of gross domestic product (GDP) and population. Empirical analysis shows that only GDP is necessary for a regression with a high coefficient of determination (R^2). Therefore, a baseline amount of MSW generated nationally is computed in Equation 2B-1. This amount if further adjusted in the model in a manner discussed later. Therefore:

$$MSW = \alpha + \beta \; x \; MC\_GDP_T \qquad \textbf{(2B-1)}$$

where:

MSW	=	Quantity of municipal solid waste generated in the United States,
α	=	an econometrically estimated parameter for the intercept,
β	=	an econometrically estimated parameter for the slope,
T	=	current NEMS year, and
MC_GDP_T	=	real gross domestic product for year T.

The Analysis of Variance, with MSW as the dependent variable, yielded the following:

Parameter	DF	Parameter Estimate	Standard Error	Probability >|T|	T for HO Param.=0
$\hat{\alpha}$	1	14.60056435	5.33926732	0.0411	2.735
$\hat{\beta}$	1	0.03599054	0.001522472	0.0001	23.640

Durbin-Watson D - 2.501
Number of Observations - 7

F Value	PROB> F	R-Square	Adjusted R-Square
558.828	0.0001	0.9911	0.9894

The data values shown in Table 2B-1 below were used in the regression, with Gross National Product serving as a proxy for Gross Domestic Product.

Table 2B-1. Historical MSW Quantity and GNP Values

Year	Historical MSW Quantity (Million of Tons)	Gross National Product (Billions of 1987 Dollars)
1960	87.8	1985.1
1965	103.4	2491.9
1970	121.9	2893.5
1975	128.1	3247.6
1980	151.4	3823.4
1985	164.4	4295.0
1990	195.7	4894.6

The adjusted R^2 of 0.9894 shows a high degree of correlation.

The model incorporates an additional factor for source reduction, discussed below, into the equation for waste generation.

Source Reduction Factor

Projections of MSW generation quantities based on the above regression approach must be modified because of structural market changes that are occurring and are likely to occur in future years. Governments and businesses have adopted strategies to lessen the amount of waste generated without reducing economic output. The general term for these strategies is *source reduction*. An example of such a strategy is the local government trend toward unit-based disposal rates, which has brought about a reduction of generated waste where implemented. Also, as of 1992 at least 38 States have passed laws mandating that disposal of their municipal waste streams be reduced by 25 percent or more by no later than the year 2000.[5] Such goals can be met through a combination of source reduction and recycling. To the extent that source reduction strategies are successful, they will likely alter the basic relationship between GDP and MSW quantity.

In order to reflect anticipated annual reductions in the quantity of MSW generated on account of source reduction efforts, the quantity projected by the MSW supply equation will be reduced by an exogenously-determined source reduction multiplier. This multiplier, *SR*, will be based in part on legislation passed or proposed to promote source reduction. Currently, EIA uses expert judgement to derive the *SR* parameter of 0.005 that is currently used in the MSW supply equation.

The quantity of waste generation, QNAT, is therefore represented as follows:

$$QNAT = MSW \; x \; [\, 1 - (T-1) \; x \; SR \,] \qquad \textbf{(2B-2)}$$

where:

QNAT	=	Projected MSW generation in the United States,
T	=	current NEMS year, and
SR	=	annual source reduction factor.

Within the MSW Submodule, Equations 2B-1 and 2B-2 are combined into a single equation:

$$QNAT = \alpha + \beta \; x \; MC\_GDP_T \; x \; [1 - (T - 1) \; x \; SR] \qquad \textbf{(2B-3)}$$

Fraction of MSW Combusted

The ORNL baseline MSW combusted fractions used in the MSW Submodule reflect an optimistic outlook for long-term market penetration of WTE facilities. This outlook is based on five major expected trends pointing toward increased reliance on WTE facilities as waste management options. First, the number of landfills is dropping rapidly and will continue to do so as recent Resource Conservation and Recovery Act (RCRA) landfill rules are put in place. Further, the cost of landfilling is likely to increase significantly both in absolute terms as well as relative to the cost of building and operating WTE facilities. Second, barriers to the financing of WTE facilities that resulted primarily from the Tax Reform Act of 1986 are likely to be overcome gradually. These financing barriers have played a role in decisions to cancel several WTE facilities. Third, the environmental effects of WTE operations continue to be assessed, and the opposition to WTE may subside somewhat as the public becomes more informed about the environmental

[5]Glenn, J., "The State of Garbage in America," *Biocycle*, May 1992, pp. 30-37.

consequences of WTE relative to other waste management options. Fourth, there is increasing speculation that the recycling goals of 25 to 50 percent mandated or targeted in many States will not be reached. If this speculation is correct, communities will turn increasingly to WTE as the preferred alternative. Finally, it is likely that the U.S. Congress will grant States limited authority to restrict the importation of MSW into their States for disposal. Recent attempts by States to restrict the importation of waste have thus far been overturned in the Courts on the grounds that such bans violate the interstate commerce provisions of the U.S. Constitution. However, if Congress allows States to limit MSW importation, many populous States will be faced with the increased burden of managing their own waste. In this event, WTE is likely to receive greater attention as a waste management option.

Because of these factors, ORNL expects that WTE will claim an increasing share of MSW management, especially beyond the year 2000.

ORNL's percent-combusted values were then adjusted using a regional estimation procedure applied by EIA staff. First, the Franklin Associates/EPA value for total waste (195.7 million tons per year) was proportionally disaggregated into Census divisions according to the populations in each Census division. This disaggregation assumes a constant per-capita MSW generation rate for all regions because there is no known data on regional MSW generation or rates.

The existing facility design capacity, in tons per day, is then identified and aggregated into Census divisions using information from Waste Age magazine.[6] A value for tons of MSW combusted is estimated by applying a utilization factor of 0.90, which is consistent with the value derived from the EPA data. The estimated combusted-shares in each Census division is obtained by dividing the tons-combusted values by the total waste generated in Census division.

The regional combusted-shares for 2010 were established based on the following rules:

1. No regional share will be above 50 percent. Thus, combusted-share values for two regions (New England and Alaska-Hawaii) decline to 50 percent. This rule is based on the assumption of increased recycling, which is expected to grow to 40 percent in many jurisdictions. At least 10 percent is expected to be landfilled in any case since some material cannot be recycled or burned.

2. The Mid-Atlantic Census Division is assumed to be limited to a combusted-share of 40 percent, since those States have more robust recycling goals.

3. Combusted-shares for all other regions are assumed to increase at an annual rate of 5 percent from 1990 through 2010.

The average of the resulting values, weighted by waste generated, is about 30 percent for 2010, which is used as the national value. Use of regional shares directly would require that these values be derived by NERC regions, and data is not readily available for such a calculation.

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[6]"The 1992 Municipal Waste Combustion Guide," *Waste Age* (November 1992).

Data used to derive the adjusted combusted-shares and results are provided in Table 2B-2. The intermediate combustion shares are linearly interpolated between 1990 and 2010.

Table 2B-2. Regional Estimates of MSW Combustion Shares, 1990 and 2010

				Percent Combusted Shares	
Census Division	1990 Population	Waste Generation (Tons per Day)	Combustion Capacity (Tons per Day)	1990	2010
New England	13,206,943	28,471.3	17,860	0.56	0.50
Mid Atlantic	37,602,286	81,062.2	15,626	0.17	0.40
East North Central	42,008,942	90,562.0	13,827	0.14	0.36
West North Central	18,867,612	40,674.0	5,743	0.13	0.34
South Atlantic	42,359,131	91,316.9	25,416	0.25	0.50
East South Central	15,176,284	32716.7	2,770	0.08	0.20
West South Central	26,702,793	57,565.3	1,773	0.03	0.07
Mountain	13,658,776	29,445.3	522	0.02	0.04
Pacific	7,709,013	16,618.9	2,560	0.14	0.37
California	29,760,021	64,156.0	1,328	0.02	0.05
Alaska-Hawaii	1,658,632	3,575.6	2,205	0.56	0.50
U.S. TOTAL	248,710,233	536,164.4	89,630	0.15	0.30

Equation 2B-4 determines the quantity shares of energy produced from MSW:

$$Q_{U,RC,S} = QNAT \times PCC_{RC,T} \times HC_{RC,T} \times F_{U,RC,S} \times 2000 \tag{2B-4}$$

where:

$Q_{U,RC,S}$	=	energy quantity produced from municipal solid waste for use U (where U_1= electricity supplied to the grid, U_2 = electricity supplied for own use, and U_3 = steam and other), sector S (where S_1 = commercial sector, S_2 = industrial sector, and S_3 = electric utility sector), in Census division RC,
$QNAT$	=	quantity of municipal solid waste generated in the United States,
$PCC_{RC,T}$	=	percent combusted for Census division RC in year T,
$HC_{RC,T}$	=	heat content for Census division RC in year T, and
$F_{U,RC,S}$	=	fraction of MSW combusted for use U in sector S in Census division RC.

Equations 2B-5 and 2B-6 combine the production capacity for all energy forms (electricity and other) into a total energy production capacity for commercial and industrial sectors:

$$WCAMSCM_{RC,T} = \sum_{U=1}^{3} Q_{U,RC,S=1} \tag{2B-5}$$

where:

$WCAMSCM_{RC,T}$	=	MSW energy production capacity in millions of Btu for the commercial sector by Census division RC in year T, and,
$Q_{U,RC,S=1}$	=	MSW energy quantity produced from municipal solid waste for use U (where U_1= electricity supplied to the grid, U_2 = electricity supplied for own use, and U_3 = steam and other), in the commercial sector (S=1) in Census division RC.

$$WCAMSIN_{RC,T} = \sum_{U=1}^{3} Q_{U,RC,S=2} \qquad \textbf{(2B-6)}$$

where:

$WCAMSIN_{RC,T}$	=	MSW energy production capacity in millions of Btu for the industrial sector by Census division *RC* in year *T*, and,
$Q_{U,RC,S=2}$	=	MSW energy quantity produced from municipal solid waste for use *U* in the industrial sector (S=2) by Census division *RC*.

Equation 2B-7 calculates the annual electric capacity available for WTE facility own-use and sale to the electric utility grid:

$$WCAMSELRC_{RC,T} = \frac{\left[\sum_{U=1}^{2} Q_{U,RC,S=3}\right] x\ 10^6}{HR1\ x\ 8760\ x\ 1000} \qquad \textbf{(2B-7)}$$

where:

$WCAMSELRC_{RC,T}$	=	Annual MSW electric capacity in megawatts for own-use and sale to the utility grid in Census division *RC* in year *T*,
HR1	=	Heat rate for MSW (Btu in/kWh out), and,
$Q_{U,RC,S=3}$	=	Annual electricity production from MSW in millions of Btu for both sale to the grid (U=1) and own-use (U=2), in the electric utility sector (S=3), in Census division *RC*.

Equation 2B-8 maps annual electric capacity from Census divisions to NERC regions:

$$WCAMSEL_{RN,T} = \sum_{RC=1}^{9} WCAMSELRC_{RC,T} \ x \ MPCRNR_{RC,RN} \qquad \textbf{(2B-8)}$$

where:

$WCAMSEL_{RN,T}$	=	Electric capacity in megawatts in NERC Region *RN* in year *T*,
$WCAMSELRC_{RC,T}$	=	Electric capacity in megawatts for Census division *RC* in year *T*, and
$MPCRNR_{RC,RN}$	=	Conversion factor matrix for mapping Census division *RC* to NERC Region *RN*.

Equation 2B-9 transforms the fuel cost (tipping fee) from dollars-per-ton units to mills-per-kilowatthour units:

$$WFCMSELM_{RN,T} = \frac{WFCMSEL_{RN,T} \ x \ WHRMSEL_{RN,T} \ x \ 1000}{WHCMSEL_{RN,T} \ x \ 2000} \qquad \textbf{(2B-9)}$$

where:

$WFCMSELM_{RN,T}$	=	Fuel cost in mills/kWh for a WTE plant for NERC Region *RN* in year *T*,
$WFCMSEL_{RN,T}$	=	Fuel cost (tipping fee) in dollars per ton for a WTE plant for NERC Region *RN* in year *T*,
$WHCMSEL_{RN,T}$	=	Heat content of MSW in NERC Region *RN* for year *T*,
2000	=	Number of pounds in a ton, and
$WHRMSEL_{RN,T}$	=	Heat rate for utilities in NERC Region *RN* in year *T*.

Equation 2B-10 calculates WTE facility variable operating costs:

$$WVCMSEL_{RN,T} = RVOM - WFCMSELM \qquad \textbf{(2B-10)}$$

where:

$WVCMSEL_{RN,T}$	=	RFM variable operating cost common block variable for WTE facilities in NERC Region *RN* in year *T*,
RVOM	=	Variable operation & maintenance cost in mills per kilowatthour,
$WFCMSELM_{RN,T}$	=	Fuel cost (tipping fee) in mills/kWh for a WTE plant for NERC Region *RN* in year *T*,

Appendix 2-C: Bibliography

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Government Advisory Associates, *Resource Recovery Yearbook*, 177 East 87th Street, New York, NY, 1991.

National Solid Waste Management Association, "The 1992 Municipal Waste Combustion Guide," *Waste Age* 23(11): pp. 99-117, November 1992.

Oak Ridge National Laboratory, "Data and Sources: Biomass Supply Draft Report," prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993, p. 13-14.

Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?*, Congress of the United States, U.S. Government Printing Office, Washington, DC, October 1989.

Appendix 2-D: Model Abstract

Model Name:
Municipal Solid Waste Submodule

Model Acronym:
MSW

Description:
The submodule uses the quantity of municipal solid waste produced (derived econometrically), the heating value of MSW, and forecasted shares of MSW combusted for energy recovery to produce forecasts of the production of electricity and other energy forms (steam and direct heat). Forecasts are disaggregated by consuming sector (commercial, industrial, and electric utility) and region.

Purpose of the Model:
The MSW Submodule provides the NEMS commercial and industrial sector modules with annual regional projections of energy produced from the incineration of municipal solid waste. For the NEMS Electricity Market Module, the submodule provides regional forecasts of electric capacity to be decremented from electric utility capacity requirements, as well as capital and operating costs for the calculation of electricity prices.

Most Recent Model Update:
December 1993

Part of Another Model?:
The MSW submodule is a component of the Renewable Fuels Module (RFM) of the National Energy Modeling System (NEMS).

Official Model Representative:
Roger Diedrich
Coal, Uranium, and Renewable Fuels Analysis Branch
Energy Information Administration
Phone: (202) 586-0829

Documentation:
Model Documentation Report: Renewable Fuels Module, March 1994.

Archive Media and Installation Manual(s):
Archived as part of the NEMS production runs.

Energy System Described:
Byproduct energy production and consumption from the combustion of municipal solid waste.

Coverage:

- Geographic: Nine Census Divisions—New England, Mid-Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific

- Time Unit/Frequency; Annual, 1990 through 2015

- Products: electricity, steam

- Economic Sectors: commercial sector, industrial sector, electric utility sector

Modeling Features:

- Model Structure: Sequential calculation of forecasted national municipal solid waste (MSW) generation, followed by derivation of regional and sector energy shares based on estimates of the percentage of MSW combusted.

- Modeling Technique: Econometric estimation of municipal solid waste generation, coupled with an energy share allocation algorithm for deriving electric generation capacity and energy quantities by sector and region.

- Special Features: Allows for the modeling of regional and national resource recovery efforts

Non-DOE Input Sources:

Franklin Associates, data prepared for the Environmental Protection Agency:

- National annual quantity of municipal solid waste generated

- Forecasted annual percentages of municipal solid waste combusted

Government Advisory Associates, *Resource Recovery Yearbook* and Resource Recovery Database:

- Plant-specific electricity generation, Btu energy content of MSW

- Plant locations and energy consuming sectors

Electric Power Research Institute, *TAG Technical Assessment Guide*:

- Capital cost; fixed and variable operation & maintenance costs

- Plant capacity factor

DOE Input Sources:

None.

Computing Environment:

- Hardware Used: IBM 3090
- Operating System: MVS
- Language/Software used: VS FORTRAN, Ver. 2.05
- Memory Requirement: 11 Kb
- Storage Requirement: 6 Kb tracks of an IBM 3380 disk pack
- Estimated Run Time: 0.02 seconds
- Special Features: None

Independent Expert Reviews Conducted:

None.

Status of Evaluation Efforts by Sponsor:

None.

Appendix 2-E: Data Quality and Estimation Processes

This Appendix discusses (1) the quality of the principal sources of input data used in the MSW Submodule, along with a discussion of user-defined parameters and guidelines used to select them, and (2) estimation methods used to derive parameters.

Governmental Advisory Associates Resource Recovery Database

The original GAA data file consists of 20 columns of data items and 202 rows corresponding to each MSW facility in the GAA database. The 20 data items include the following: plant number, status, start month, start year, planned start month, planned start year, shutdown date, State, capacity, annual throughput of MSW, output type, gross capacity (2MW), net capacity (MW), gross kWh/ton, net kWh/ton, Btu/lb, Census division, NERC Region, sector, and a consuming sector code. Census division was determined by the State, and NERC Region was determined from a map of NERC Regions and the location of the facilities in the GAA data. Allocation by sector was determined according to the primary customer, not ownership of the facility. Military installations and sewage and water treatment facilities were assumed to be part of the industrial sector. Universities, prisons, police stations, and district heating facilities were included in the commercial sector. There was considerable missing data in the GAA database, particularly for electricity generation and energy content. Data were filled in using averages across WTE facilities using the following procedures:

1. If there is no net kWh/ton, but there are data on gross kWh/ton, then use the following equation:

$$netkWh/ton = grosskWh/ton \ x \ \frac{netMW}{grossMW} \qquad \textbf{(2E-1)}$$

2. If there is no gross kWh/ton, but there are data on net kWh/ton, then use the following equation:

$$grosskWh/ton = netkWh/ton \ x \ \frac{grossMW}{netMW} \qquad \textbf{(2E-2)}$$

3. If there is no net capacity, but there are data on gross capacity, then use the following:

$$netMW = grossMW \ x \ \frac{average \ netMW}{average \ grossMW} \qquad \textbf{(2E-3)}$$

Averages were determined for all plants generating electricity however, averages differentiated between those plants that generate only electricity and those cogenerating electricity and steam.

4. If there is no net capacity or gross capacity, the following two equations were used.

$$etMW = annual \ throughput \ of \ MSW \ x \ \frac{average \ netMW}{average \ throughpu} \qquad \textbf{(2E-4)}$$

$$ossMW = annual \ throughput \ of \ MSW \ x \ \frac{average \ grossM}{average \ throughp} \qquad \textbf{(2E-5)}$$

Averages differentiate between electricity only and cogeneration facilities.

5. If there is no net kWh/ton or gross kWh/ton, then use the following two equations.

$$grosskWh/ton = average \ grosskWh/ton \qquad \textbf{(2E-6)}$$

$$netkWh/ton = grosskWh/ton \ x \ \frac{netMW}{grossMW} \qquad \textbf{(2E-7)}$$

6. If there is no heat content (Btu/lb), then use the following equation.

$$Btu/lb = average \ Btu/lb \qquad \textbf{(2E-8)}$$

In this case, the average heat content is computed across all facilities regardless of the output.

The GAA data file was then reduced to include only those data items necessary for calculating *F*, *HR*, and *MPCRNR*. This reduced data file is used as input to the FORTRAN program that determines *F*, *HR*, and *MPCRNR*.

The raw data from the GAA database, with no missing values filled in, are shown in Table 2E-1. This table also shows the sector codes indicating the end-use sector to which the energy is sold.[7] Table 2E-2 shows the data with missing data filled in. In this table, the WTE plants are sorted by output type and Census region within output type. The column names for both tables are as follows: 1=plant number, 2=status, 3=start month, 4=start year, 5=planned start month, 6=planned start year, 7=month closed, 8=year closed, 9=State, 10=average daily throughput of MSW (tons/day), 11=annual throughput of MSW (tons/year), 12=type of energy output, 13=gross MW_e capacity, 14=net MW_e capacity, 15=gross kWh_e/ton of MSW, 16=net kWh_e/ton of MSW, 17=Btu/ton of MSW, 18=census region, 19=NERC region, 20=sector(s) to which energy from MSW sold, and 21=sector code.

[7]Determining what sector to allocate the energy production was based on the judgment of ORNL Energy Division staff.

Table 2E-1. Plant-Level Data from the GAA Database with Sector Codes Added

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	8	4	84			3	86	AL	50	13000	1	0	0	0	0	0	6	9	i
2	5	7	90					AL	586	221000	1	0	0	0	0	0	6	9	i
3	5	3	84					AL	290	100000	1	0	0	0	0	0	6	9	i
4	5	6	81					AK	45	15435	5	0	0	0	0	0	9	11	c
5	4			9	90			AK	200	60000	4	0	0	0	0	0	9	11	c
6	5	5	85					AK	20	5500	1	0	0	0	0	0	9	11	c
7	5	5	81					AR	94	22598	1	0	0	0	0	0	7	10	i
8	5	1	80					AR	45	16200	1	0	0	0	0	0	7	10	i
9	5	5	87					CA	380	110000	2	11.5	10	725	630	5600	9	13	u
10	5	1	89					CA	730	293000	2	22.5	17		450	4750	9	13	u
11	4	12	88					CA	1170	427000	2	36	30		540	4800	9	13	u
12	2			10	94			CA	1822	638000	2	41	36		540	4900	9	13	u
13	8	11	84	7	91	5	85	CA	100	36500	3	1.54	1.2			6500	9	13	uc
14	5	7	88					CT	2000	720000	2	67	60	720	640	5300	1	7	u
15	5	3	88					CT	600	195000	2	16	13.5	620	535	5000	1	7	u
16	2			3	94			CT	468	170638	2	14.5	12		560	5300	1	7	u
17	5	10	88					CT	2300	624000	2	90	68.5			5500	1	7	u
18	2			3	93			CT	425	131750	2	15	13	600	550	4500	1	7	u
19	3			10	91			CT	522	190530	2	18	16		520	5000	1	7	u
20	5	5	89					CT	380	138000	3	11	9.3	500	384	4850	1	7	ui
21	5	11	81					CT	130	37000	3	2.2	1.9	150		5000	1	7	u
22	5	3	84					DE	600	230000	4	0	0	0	0	0	5	3	u
23	5	11	87					DE	546	200000	3	13.3	10.5		532	5500	5	3	ui
24	5	10	87					FL	1200	430000	2	30	27.5		492	4500	5	8	u
25	3			1	92			FL	2250	821250	2	63.4	57	676	608	5200	5	8	u
26	8	4	89			9	89	FL	540	140400	4	0	0	0	0	0	5	8	i
27	5	12	86					FL	130	46538	2	2.6	2.2		300	5000	5	8	u
28	5	7	83					FL	275	63250	2	364	335			4500	5	8	u
29	2			1	94			FL	1530	558450	2	50	47		630	5000	5	8	u
30	5	12	79					FL	33	10296	1	0	0	0	0	0	5	8	i
31	5	1	82					FL	2800	1022000	2	77	62	480	388	5000	5	8	u
32	6	11	83					FL	25	9125	1	0	0	0	0	0	5	8	c
33	4			3	91			FL	449	163000	2	14.5	10	25		5000	5	8	u
34	5	6	87					FL	435	186642	2	12	10	480	432	4600	5	8	u
35	3			1	92			FL	660	207000	4	0	0	0	0	0	5	8	i
36	5	5	83					FL	2835	920000	2	62	55.8		430	4000	5	8	u
37	3			1	92			FL	2250	821250	2	66.5	60	709	638	5200	5	8	u
38	5	11	89					FL	2000	624000	2	61	49	600	500	4865	5	8	u
39	3			7	91			FL	893	325945	2	31	29	650	550	4800	5	8	u
40	5	9	85					FL	844	306000	2	17	15		450	5000	5	8	u
41	5	6	87					GA	480	175200	1	0	0	0	0	0	5	9	i
42	5	5	90					HI	1740	600000	2	55	46	550		4800	9	13	u

Table 2E-1. Plant-Level Data from the GAA Database with Sector Codes Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
43	5	12	82					ID	50	8308	1	0	0	0	0	0	8	11	i
44	5	9	70					IL	1250	400000	3	0	0				3	4	ui
45	2							IL	380	144000	3	8	6		380	0	3	4	u
46	2			1	94			IL	1020	379746	2	50	41		800	6100	3	4	u
47	2			7	95			IN	367	113867	3	10.5	8.9			0	3	1	u
48	5	11	88					IN	2173	701830	1	0	0	0	0	0	3	1	u
49	5	9	90					IN	125	32500	4	0	0	0	0	0	3	1	i
50	5	9	75					IA	174	43500	2	100	95			6200	4	5	u
51	5	10	88					IA	100	25500	4	0	0	0	0	0	4	5	i
52	3			7	92			ME	176	64240	2	5	3.8			5200	1	7	u
53	5	12	87					ME	607	221555	2	22	20			6200	1	7	u
54	5	6	88					ME	750	215000	2	25.3	21	545	455	6200	1	7	u
55	5	9	88					ME	500	163000	2	13.6	10	500		5000	1	7	u
56	5	5	85					MD	1947	710500	3	60	34	400	350	5100	5	3	u
57	6	1	76					MD	600	186000	2	200	188			6800	5	3	u
58	2			3	94			MD	1530	558450	2	83.6	69		644	5500	5	3	u
59	5	1	88					MD	327	119241	1	0	0	0	0	0	5	3	i
60	5	8	88					MA	324	112500	3	8.6	7.1		390	4200	1	7	u
61	2			1	95			MA	1275	465000	2	50	40			5500	1	7	u
62	5	6	89					MA	1518	550000	2	46	41		572	5081	1	7	u
63	5	3	85					MA	610	222000	3	21	17			6000	1	7	ui
64	5	1	88					MA	1500	532500	2	40	36		600	5000	1	7	u
65	5	9	85					MA	1350	435000	2	38	32		550	5500	1	7	u
66	5	3	81					MA	230	80000	1	0	0	0	0	0	1	7	i
67	5	10	88					MA	1800	630000	2	52	45		570	5000	1	7	u
68	5	10	75					MA	1200	438000	2	50	40		550	4500	1	7	u
69	2			1	94			MI	1700	620500	2	62	54		645	5200	3	1	u
70	5	7	89					MI	2900	754000	3	65				0	3	1	uc
71	5	1	90					MI	625	194000	3	18.3	15.7		410	5350	3	1	uc
72	5	10	87					MI	200	70000	3	2	1.7			4900	3	1	c
73	2				93			MI	150	54750	3	2.8	2.3		373	0	3	1	ui
74	2				94			MI	476	173740	2	13	11			6000	3	1	u
75	5	4	87					MN	50	18000	1	0	0	0	0	0	4	5	ic
76	5	11	81					MN	22	6500	1	0	0	0	0	0	4	5	c
77	5	3	81					MN	300	77000	1	0	0	0	0	8000	4	5	i
78	5	3	87					MN	470	120000	4	0	0	0	0	0	4	5	u i
79	5	8	89					MN	1500	460500	2	35			700	5500	4	5	u
80	5	2	88					MN	75	27375	1	0	0	0	0	0	4	5	i
81	5	3	88					MN	80	25000	1	0	0	0	0	0	4	5	i
82	5	3	90					MN	1000	365000	2	37.5	33	700	540	5800	4	5	u
83	5	7	87					MN	1175	400000	2	22	19.5			5500	4	5	u

Table 2E-1. Plant-Level Data from the GAA Database with Sector Codes Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
84	5	9	86					MN	100	33000	1	0	0	0	0	0	4	5	i
85	5	9	82					MN	85	22000	1	0	0	0	0	0	4	5	i
86	5	3	87					MN	190	59000	3	3	2.25	293		5500	4	5	u
87	2			3	93			MN	640	233600	2	23	20		550	5000	4	5	u
88	5	12	82					MN	68	22440	1	0	0	0	0	0	4	5	i
89	5	11	85					MN	50	10000	4	0	0	0	0	0	4	5	c
90	5	1	85					MS	120	37000	1	0	0	0	0	0	6	10	i
91	5	3	82					MO	30	10950	1	0	0	0	0	0	4	10	i
92	6	5	82					MT	75	15000	1	0	0	0	0	0	8	11	u
93	2			1	95			NV	712	260000	3	50	40			0	8	11	u
94	5	3	87					NH	180	65000	2	4.5	3.8	440		5400	1	7	u
95	5	9	80					NH	100	36500	1	0	0	0	0	0	1	7	c
96	2				94			NH	504	183960	2	14	12.5		425	4500	1	7	u
97	5	9	89					NH	425	155000	2	13	12	550	470	5000	1	7	u
98	3			3	91			NJ	840	306600	2	30	21		482	4500	2	3	u
99	2			10	93			NJ	830	302500	2	36	32	655	560	5000	2	3	u
100	2				93			NJ	1265	438000	2	45	38.25		455	4500	2	3	u
101	3			10	90			NJ	2000	725000	2	76	72	501		4500	2	3	u
102	5	7	88					NJ	450	124100	2	13.5	10.5		482	4650	2	3	u
103	2			9	93			NJ	1219	400000	2	45	37.3	753	625	5500	2	3	u
104	3				94			NJ	425	156000	2	12.5	9.8		425	5200	2	3	u
105	2			1	93			NJ	1200	437000	2	44	39	670	567	5400	2	3	u
106	2				95			NJ	2400	876000	2	88	80		482	4500	2	3	u
107	2			10	94			NJ	1166	425517	2	40	34	535		5500	2	3	u
108	2			7	95			NJ	1445	527425	2	63	57			4950	2	3	u
109	5	5	90					NJ	525	165000	2	14	12	475	425	4500	2	3	u
110	5	12	86					NJ	60	15600	1	0	0	0	0	0	2	3	i
111	5	2	81					NY	720	148000	4	0	0	0	0	0	2	6	c
112	5	4	81					NY	500	147000	1	0	0	0	0	0	2	6	c
113	5	4	89					NY	640	210000	2	17	14		410	5000	2	6	u
114	2			1	94			NY	1275	465000	2	50	40			5500	2	6	u
115	2				95			NY	2550	930750	1	0	0	0	0	0	2	6	c
116	5	2	83					NY	130	46500	1	0	0	0	0	0	2	6	i
117	3			3	92			NY	638	253000	2	25	21	736	627	6000	2	6	u
118	5	8	83					NY	225	78750	3	2.5	1			5000	2	6	ui
119	3			10	91			NY	345	126000	2	13	11			5500	2	6	u
120	5	6	89					NY	450	160000	2	11.5	8		370	4450	2	6	u
121	2			2	93			NY	485	165000	2	18	15	560	467	5200	2	6	u
122	5	2	88					NY	170	62050	2	4.5	3			5000	2	6	u
123	5	12	80					NY	1800	583900	3	50	30			0	2	6	ui
124	2			10	93			NY	850	300000	2	31	27			6000	2	6	u

Table 2E-1. Plant-Level Data from the GAA Database with Sector Codes Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
125	2			10	93			NY	850	310000	2	38	32		640	6000	2	6	u
126	5	10	84					NY	1890	657000	2	60	55.5		590	4800	2	6	u
127	2				95			NY	900	328500	2	21	17		0	0	2	6	u
128	5	10	88					NY	400	120000	3	10	9.2	320	140	0	2	6	ui
129	5		64					NY	800	292000	1	0	0	0	0	0	2	6	ic
130	5	1	85					NY	160	55000	3	2.2	1.2			0	2	6	ui
131	5	2	86					NY	190	70000	3	3.6	1		275	5000	2	6	ui
132	5	5	90					NY	2505	914000	2	72	64		570	4500	2	6	u
133	5	6	89					NC	195	71000	3	5.3	4	476	395	4500	5	9	uc
134	2				92			NC	300	106500	3	5	4.25			0	5	9	ui
135	2			6	93			NC	400	140400	2	6.8	5.5		550	0	5	9	u
136	7	6	84					NC	85	51000	3	4	2			0	5	9	ui
137	5	6	79					OH	965	265000	3	4				4800	3	1	xc
138	5	6	83					OH	1600	584000	2	37	32		491	4800	3	1	u
139	5	8	88					OH	255	93075	2	6	5.7	550	523	5000	3	1	u
140	2				93			OH	810	225000	2	18.6	17.7	507	482	5000	3	1	u
141	6	11	82					OK	72	19000	1	0	0	0	0	0	7	10	i
142	8		85	1	93	9	86	OK	700	300000	2	21.8	10			5200	7	10	u
143	5	3	86					OK	1060	346960	3	16.5	14.5	600	530	5000	7	10	u
144	5	5	86					OR	535	190000	2	13.1	11		450	4700	9	11	u
145	2			7	93			PA	2250	700000	2	72	60	0	0	0	2	3	u
146	3			6	91			PA	2285	834000	2	90	80		600	5200	2	3	u
147	3			5	91			PA	1080	330000	2	36	30		560	5000	2	3	u
148	2			1	92			PA	63	21716	3	0.75	0.35	275	130	4500	2	3	i
149	2			1	93			PA	1925	700000	2	72	65		600	5200	2	3	u
150	2			1	94			PA	425	155000	2	14	12.5		525	5200	2	3	u
151	5	10	72					PA	620	200000	3	8.2	5.25		500	4500	2	1	ui
152	5	3	88					PA	40	14200	1	0	0	0	0	4500	2	3	c
153	5	11	89					PA	1100	378000	2	35	30.2		540	4500	2	1	u
154	3			1	92			PA	1200	277000	2	34	29	460		4500	2	3	u
155	2			7	93			PA	1275	465375	2	45	40			5200	2	3	u
156	2			5	93			PR	855	300000	2	27	22		510	4500			u
157	2			9	93			RI	641	234000	2	21	17		543	5200	1	7	u
158	2			4	93			RI	645	238000	3	21	18		455	4750	1	7	ui
159	5	10	85					SC	200	72000	1	0	0	0	0	0	5	9	i
160	5	11	89					SC	600	210000	3	12.8	10.8			5000	5	9	ui
161	5	12	89					SD	65	16900	4	0	0	0	0	0	4	5	c
162	5	9	80					TN	82	26000	1	0	0	0	0	0	6	9	i
163	5	12	81					TN	180	60000	3	0.5	0.43			0	6	9	ui
164	5	1	88					TN	50	18250	1	0	0	0	0	0	6	9	i
165	5	10	89					TN	48	12480	4	0	0	0	0	8000	6	9	i

Table 2E-1. Plant-Level Data from the GAA Database with Sector Codes Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
166	3			12	92			TN	205	75000	3	4	3.25			6000	6	9	ui
167	5	2	74					TN	950	346750	3	7.3	2.9			4900	6	9	uc
168	4	10	90					TN	50	13000	4	0	0	0	0	0	6	9	i
169	2			7	92			TN	170	62050	1	0	0	0	0	0	6	9	i
170	5	1	86					TX	39	13767	1	0	0	0	0	0	7	2	i
171	5	8	86					TX	35	8190	1	0	0	0	0	0	7	2	i
172	5	3	86					TX	85	20400	2	0.86	0.66			4500	7	2	u
173	5	2	80					TX	4	832	1	0	0	0	0	0	7	2	c
174	5	2	80					TX	9	1872	1	0	0	0	0	0	7	2	c
175	6	6	82					TX	48	14736	1	0	0	0	0	0	7	2	i
176	5	10	88					UT	350	127750	1	0	0	0	0	0	8	11	i
177	5	2	88					VA	940	338400	2	22	19.8	520	470	4800	5	1	u
178	5	1	86					VA	42	8400	1	0	0	0	0	0	5	9	i
179	5	10	80					VA	200	72500	1	0	0	0	0	0	5	9	c
180	5	11	82					VA	65	23725	1	0	0	0	0	0	5	9	c
181	5	6	90					VA	2700	985150	2	85	73	610	540	4400	5	1	u
182	8	5	67		94	10	86	VA	150	54750	1	0	0	0	0	0	5	9	i
183	2				93			VA	700	182000	2	12	9			0	5	9	u
184	5	1	88					VA	1400	364000	3	40	35			5550	5	9	i
185	5	7	78					VA	90	23400	1	0	0	0	0	0	5	1	i
186	8	1	88	7	91	8	88	VT	204	75000	2	7	6		470	0	1	5	u
187	5	11	86					WA	100	35000	2	1.5	1		350	4500	9	11	u
188	3			1	92			WA	110	40150	1	0	0	0	0	0	9	11	i
189	2				95			WA	2200	803000	2	90	77		565	5000	9	11	u
190	5	7	88					WA	150	54000	2	2.4	2.04		345	4500	9	11	u
191	3			8	91			WA	680	248200	2	26	22.1		497	0	9	11	u
192	5	7	79					WA	450	117000	4	0	0	0	0	0	9	11	u
193	5	3	90					WA	250	100000	2	50	43			5600	9	11	u
194	3				91			WV	550	132000	4	0	0	0	0	0	5	1	i
195	5	10	86					WI	80	29000	3	0.27	0.07			4750	3	5	ui
196	5	7	88					WI	225	56000	2	30	28			5500	3	4	u
197	5	1	79					WI	250	65000	2	100				5759	3	4	u
198	5	5	89					WI	80	22880	3	1.4	0.8	150	100	5450	3	4	ui
199	5	3	89					WI	105	33600	3	1.2	0.7	110	85	5000	3	5	uc
200	2				93			WI	128	46500	2	2.75	2.5	323	263	5000	3	4	u
201	5	6	79					WI	143	51480	1	0	0	0	0	0	3	4	i
202	2			1	94			WI	510	219000	3					5500	3	4	u

Table 2E-2. Plant-Level Data with Missing Values Filled In and Sector Code Added

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
66	5	3	81					MA	230	80000	1	0	0	0	0	5253	1	7	i	2
95	5	9	80					NH	100	36500	1	0	0	0	0	5253	1	7	c	1
112	5	4	81					NY	500	147000	1	0	0	0	0	5253	2	6	c	1
110	5	12	86					NJ	60	15600	1	0	0	0	0	5253	2	3	i	2
115	2				95			NY	2550	930750	1	0	0	0	0	5253	2	6	c	1
152	5	3	88					PA	40	14200	1	0	0	0	0	4500	2	3	c	1
116	5	2	83					NY	130	46500	1	0	0	0	0	5253	2	6	i	2
129	5		64					NY	800	292000	1	0	0	0	0	5253	2	6	ic	4
201	5	6	79					WI	143	51480	1	0	0	0	0	5253	3	4	i	2
48	5	11	88					IN	2173	701830	1	0	0	0	0	5253	3	1	u	3
75	5	4	87					MN	50	18000	1	0	0	0	0	5253	4	5	ic	4
76	5	11	81					MN	22	6500	1	0	0	0	0	5253	4	5	c	1
81	5	3	88					MN	80	25000	1	0	0	0	0	5253	4	5	i	2
84	5	9	86					MN	100	33000	1	0	0	0	0	5253	4	5	i	2
85	5	9	82					MN	85	22000	1	0	0	0	0	5253	4	5	i	2
88	5	12	82					MN	68	22440	1	0	0	0	0	5253	4	5	i	2
80	5	2	88					MN	75	27375	1	0	0	0	0	5253	4	5	i	2
91	5	3	82					MO	30	10950	1	0	0	0	0	5253	4	10	i	2
77	5	3	81					MN	300	77000	1	0	0	0	0	8000	4	5	i	2
59	5	1	88					MD	327	119241	1	0	0	0	0	5253	5	3	i	2
185	5	7	78					VA	90	23400	1	0	0	0	0	5253	5	1	i	2
30	5	12	79					FL	33	10296	1	0	0	0	0	5253	5	8	i	2
159	5	10	85					SC	200	72000	1	0	0	0	0	5253	5	9	i	2
32	6	11	83					FL	25	9125	1	0	0	0	0	5253	5	8	c	1
178	5	1	86					VA	42	8400	1	0	0	0	0	5253	5	9	i	2
179	5	10	80					VA	200	72500	1	0	0	0	0	5253	5	9	c	1
41	5	6	87					GA	480	175200	1	0	0	0	0	5253	5	9	i	2
182	8	5	67		94	10	86	VA	150	54750	1	0	0	0	0	5253	5	9	i	2
180	5	11	82					VA	65	23725	1	0	0	0	0	5253	5	9	c	1
90	5	1	85					MS	120	37000	1	0	0	0	0	5253	6	10	i	2
1	8	4	84			3	86	AL	50	13000	1	0	0	0	0	5253	6	9	i	2
3	5	3	84					AL	290	100000	1	0	0	0	0	5253	6	9	i	2
2	5	7	90					AL	586	221000	1	0	0	0	0	5253	6	9	i	2
164	5	1	88					TN	50	18250	1	0	0	0	0	5253	6	9	i	2
162	5	9	80					TN	82	26000	1	0	0	0	0	5253	6	9	i	2
169	2			7	92			TN	170	62050	1	0	0	0	0	5253	6	9	i	2
175	6	6	82					TX	48	14736	1	0	0	0	0	5253	7	2	i	2
7	5	5	81					AR	94	22598	1	0	0	0	0	5253	7	10	i	2
141	6	11	82					OK	72	19000	1	0	0	0	0	5253	7	10	i	2
8	5	1	80					AR	45	16200	1	0	0	0	0	5253	7	10	i	2

Table 2E-2. Plant-Level Data with Missing Values Filled In and Sector Code Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
171	5	8	86					TX	35	8190	1	0	0	0	0	5253	7	2	i	2
170	5	1	86					TX	39	13767	1	0	0	0	0	5253	7	2	i	2
174	5	2	80					TX	9	1872	1	0	0	0	0	5253	7	2	c	1
173	5	2	80					TX	4	832	1	0	0	0	0	5253	7	2	c	1
92	6	5	82					MT	75	15000	1	0	0	0	0	5253	8	11	u	3
43	5	12	82					ID	50	8308	1	0	0	0	0	5253	8	11	i	2
176	5	10	88					UT	350	127750	1	0	0	0	0	5253	8	11	i	2
188	3			1	92			WA	110	40150	1	0	0	0	0	5253	9	11	i	2
6	5	5	85					AK	20	5500	1	0	0	0	0	5253	9	11	c	1
156	2			5	93			PR	855	300000	2	27	22	626	510	4500			u	3
61	2			1	95			MA	1275	465000	2	50	40	620	496	5500	1	7	u	3
68	5	10	75					MA	1200	438000	2	50	40	688	550	4500	1	7	u	3
62	5	6	89					MA	1518	550000	2	46	41	642	572	5081	1	7	u	3
65	5	9	85					MA	1350	435000	2	38	32	653	550	5500	1	7	u	3
64	5	1	88					MA	1500	532500	2	40	36	667	600	5000	1	7	u	3
67	5	10	88					MA	1800	630000	2	52	45	659	570	5000	1	7	u	3
97	5	9	89					NH	425	155000	2	13	12	550	470	5000	1	7	u	3
96	2				94			NH	504	183960	2	14	12.5	476	425	4500	1	7	u	3
94	5	3	87					NH	180	65000	2	4.5	3.8	440	372	5400	1	7	u	3
17	5	10	88					CT	2300	624000	2	90	68.5	620	472	5500	1	7	u	3
157	2			9	93			RI	641	234000	2	21	17	671	543	5200	1	7	u	3
19	3			10	91			CT	522	190530	2	18	16	585	520	5000	1	7	u	3
18	2			3	93			CT	425	131750	2	15	13	600	550	4500	1	7	u	3
16	2			3	94			CT	468	170638	2	14.5	12	677	560	5300	1	7	u	3
55	5	9	88					ME	500	163000	2	13.6	10	500	368	5000	1	7	u	3
14	5	7	88					CT	2000	720000	2	67	60	720	640	5300	1	7	u	3
186	8	1	88	7	91	8	88	VT	204	75000	2	7	6	548	470	5253	1	5	u	3
15	5	3	88					CT	600	195000	2	16	13.5	620	535	5000	1	7	u	3
52	3			7	92			ME	176	64240	2	5	3.8	620	471	5200	1	7	u	3
53	5	12	87					ME	607	221555	2	22	20	620	564	6200	1	7	u	3
54	5	6	88					ME	750	215000	2	25.3	21	545	455	6200	1	7	u	3
109	5	5	90					NJ	525	165000	2	14	12	475	425	4500	2	3	u	3
107	2			10	94			NJ	1166	425517	2	40	34	535	455	5500	2	3	u	3
104	3				94			NJ	425	156000	2	12.5	9.8	542	425	5200	2	3	u	3
105	2			1	93			NJ	1200	437000	2	44	39	670	567	5400	2	3	u	3
106	2				95			NJ	2400	876000	2	88	80	530	482	4500	2	3	u	3
108	2			7	95			NJ	1445	527425	2	63	57	620	561	4950	2	3	u	3
101	3			10	90			NJ	2000	725000	2	76	72	501	475	4500	2	3	u	3
103	2			9	93			NJ	1219	400000	2	45	37.3	753	625	5500	2	3	u	3
102	5	7	88					NJ	450	124100	2	13.5	10.5	620	482	4650	2	3	u	3
146	3			6	91			PA	2285	834000	2	90	80	675	600	5200	2	3	u	3

Table 2E-2. Plant-Level Data with Missing Values Filled In and Sector Code Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
147	3			5	91			PA	1080	330000	2	36	30	672	560	5000	2	3	u	3
145	2			7	93			PA	2250	700000	2	72	60	620	517	5253	2	3	u	3
127	2				95			NY	900	328500	2	21	17	620	502	5253	2	6	u	3
132	5	5	90					NY	2505	914000	2	72	64	641	570	4500	2	6	u	3
154	3			1	92			PA	1200	277000	2	34	29	460	392	4500	2	3	u	3
155	2			7	93			PA	1275	465375	2	45	40	620	551	5200	2	3	u	3
153	5	11	89					PA	1100	378000	2	35	30.2	626	540	4500	2	1	u	3
149	2			1	93			PA	1925	700000	2	72	65	665	600	5200	2	3	u	3
150	2			1	94			PA	425	155000	2	14	12.5	588	525	5200	2	3	u	3
119	3			10	91			NY	345	126000	2	13	11	620	525	5500	2	6	u	3
120	5	6	89					NY	450	160000	2	11.5	8	532	370	4450	2	6	u	3
117	3			3	92			NY	638	253000	2	25	21	736	627	6000	2	6	u	3
113	5	4	89					NY	640	210000	2	17	14	498	410	5000	2	6	u	3
114	2			1	94			NY	1275	465000	2	50	40	620	496	5500	2	6	u	3
125	2			10	93			NY	850	310000	2	38	32	760	640	6000	2	6	u	3
126	5	10	84					NY	1890	657000	2	60	55.5	638	590	4800	2	6	u	3
124	2			10	93			NY	850	300000	2	31	27	620	540	6000	2	6	u	3
121	2			2	93			NY	485	165000	2	18	15	560	467	5200	2	6	u	3
122	5	2	88					NY	170	62050	2	4.5	3	620	413	5000	2	6	u	3
98	3			3	91			NJ	840	306600	2	30	21	689	482	4500	2	3	u	3
99	2			10	93			NJ	830	302500	2	36	32	655	560	5000	2	3	u	3
100	2				93			NJ	1265	438000	2	45	38.25	535	455	4500	2	3	u	3
138	5	6	83					OH	1600	584000	2	37	32	568	491	4800	3	1	u	3
139	5	8	88					OH	255	93075	2	6	5.7	550	523	5000	3	1	u	3
74	2				94			MI	476	173740	2	13	11	620	525	6000	3	1	u	3
69	2			1	94			MI	1700	620500	2	62	54	741	645	5200	3	1	u	3
140	2				93			OH	810	225000	2	18.6	17.7	507	482	5000	3	1	u	3
200	2				93			WI	128	46500	2	2.75	2.5	323	263	5000	3	4	u	3
197	5	1	79					WI	250	65000	2	100	86.88	620	539	5759	3	4	u	3
196	5	7	88					WI	225	56000	2	30	28	620	579	5500	3	4	u	3
46	2			1	94			IL	1020	379746	2	50	41	976	800	6100	3	4	u	3
50	5	9	75					IA	174	43500	2	100	95	620	589	6200	4	5	u	3
82	5	3	90					MN	1000	365000	2	37.5	33	700	540	5800	4	5	u	3
79	5	8	89					MN	1500	460500	2	35	30.41	700	608	5500	4	5	u	3
87	2			3	93			MN	640	233600	2	23	20	633	550	5000	4	5	u	3
83	5	7	87					MN	1175	400000	2	22	19.5	620	550	5500	4	5	u	3
28	5	7	83					FL	275	63250	2	364	335	620	571	4500	5	8	u	3
25	3			1	92			FL	2250	821250	2	63.4	57	676	608	5200	5	8	u	3
24	5	10	87					FL	1200	430000	2	30	27.5	537	492	4500	5	8	u	3
27	5	12	86					FL	130	46538	2	2.6	2.2	355	300	5000	5	8	u	3
135	2			6	93			NC	400	140400	2	6.8	5.5	680	550	5253	5	9	u	3

Table 2E-2. Plant-Level Data with Missing Values Filled In and Sector Code Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
38	5	11	89					FL	2000	624000	2	61	49	600	500	4865	5	8	u	3
34	5	6	87					FL	435	186642	2	12	10	480	432	4600	5	8	u	3
36	5	5	83					FL	2835	920000	2	62	55.8	478	430	4000	5	8	u	3
37	3			1	92			FL	2250	821250	2	66.5	60	709	638	5200	5	8	u	3
39	3			7	91			FL	893	325945	2	31	29	650	550	4800	5	8	u	3
31	5	1	82					FL	2800	1022000	2	77	62	480	388	5000	5	8	u	3
29	2			1	94			FL	1530	558450	2	50	47	670	630	5000	5	8	u	3
40	5	9	85					FL	844	306000	2	17	15	510	450	5000	5	8	u	3
33	4			3	91			FL	449	163000	2	14.5	10	525	362	5000	5	8	u	3
57	6	1	76					MD	600	186000	2	200	188	620	583	6800	5	3	u	3
181	5	6	90					VA	2700	985150	2	85	73	610	540	4400	5	1	u	3
58	2			3	94			MD	1530	558450	2	83.6	69	780	644	5500	5	3	u	3
183	2				93			VA	700	182000	2	12	9	620	465	5253	5	9	u	3
177	5	2	88					VA	940	338400	2	22	19.8	520	470	4800	5	1	u	3
172	5	3	86					TX	85	20400	2	0.86	0.66	620	476	4500	7	2	u	3
142	8		85	1	93	9	86	OK	700	300000	2	21.8	10	620	284	5200	7	10	u	3
9	5	5	87					CA	380	110000	2	11.5	10	725	630	5600	9	13	u	3
187	5	11	86					WA	100	35000	2	1.5	1	525	350	4500	9	11	u	3
42	5	5	90					HI	1740	600000	2	55	46	550	460	4800	9	13	u	3
191	3			8	91			WA	680	248200	2	26	22.1	585	497	5253	9	11	u	3
10	5	1	89					CA	730	293000	2	22.5	17	596	450	4750	9	13	u	3
144	5	5	86					OR	535	190000	2	13.1	11	536	450	4700	9	11	u	3
190	5	7	88					WA	150	54000	2	2.4	2.04	406	345	4500	9	11	u	3
11	4	12	88					CA	1170	427000	2	36	30	648	540	4800	9	13	u	3
193	5	3	90					WA	250	100000	2	50	43	620	533	5600	9	11	u	3
189	2				95			WA	2200	803000	2	90	77	660	565	5000	9	11	u	3
12	2			10	94			CA	1822	638000	2	41	36	615	540	4900	9	13	u	3
21	5	11	81					CT	130	37000	3	2.2	1.9	150	130	5000	1	7	u	3
20	5	5	89					CT	380	138000	3	11	9.3	500	384	4850	1	7	ui	6
60	5	8	88					MA	324	112500	3	8.6	7.1	472	390	4200	1	7	u	3
63	5	3	85					MA	610	222000	3	21	17	505	409	6000	1	7	ui	6
158	2			4	93			RI	645	238000	3	21	18	531	455	4750	1	7	ui	6
130	5	1	85					NY	160	55000	3	2.2	1.2	505	275	5253	2	6	ui	6
128	5	10	88					NY	400	120000	3	10	9.2	320	140	5253	2	6	ui	6
118	5	8	83					NY	225	78750	3	2.5	1	505	202	5000	2	6	ui	6
123	5	12	80					NY	1800	583900	3	50	30	505	303	5253	2	6	ui	6
151	5	10	72					PA	620	200000	3	8.2	5.25	781	500	4500	2	1	ui	6
131	5	2	86					NY	190	70000	3	3.6	1	990	275	5000	2	6	ui	6
148	2			1	92			PA	63	21716	3	0.75	0.35	275	130	4500	2	3	i	2
198	5	5	89					WI	80	22880	3	1.4	0.8	150	100	5450	3	4	ui	6
195	5	10	86					WI	80	29000	3	0.27	0.07	505	131	4750	3	5	ui	6

Table 2E-2. Plant-Level Data with Missing Values Filled In and Sector Code Added (Continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
47	2			7	95			IN	367	113867	3	10.5	8.9	505	428	5253	3	1	u	3
73	2		93					MI	150	54750	3	2.8	2.3	454	373	5253	3	1	ui	6
72	5	10	87					MI	200	70000	3	2	1.7	505	429	4900	3	1	c	1
71	5	1	90					MI	625	194000	3	18.3	15.7	478	410	5350	3	1	uc	5
45	2							IL	380	144000	3	8	6	507	380	5253	3	4	u	3
202	2			1	94			WI	510	219000	3	16.5	12.19	505	374	5500	3	4	u	3
44	5	9	70					IL	1250	400000	3	30.1	22.26	505	374	5253	3	4	ui	6
70	5	7	89					MI	2900	754000	3	65	48.11	505	374	5253	3	1	uc	5
137	5	6	79					OH	965	265000	3	4	2.961	505	0	4800	3	1	c	1
199	5	3	89					WI	105	33600	3	1.2	0.7	110	85	5000	3	5	uc	5
86	5	3	87					MN	190	59000	3	3	2.25	293	220	5500	4	5	u	3
184	5	1	88					VA	1400	364000	3	40	35	505	442	5550	5	9	i	2
56	5	5	85					MD	1947	710500	3	60	34	400	350	5100	5	3	u	3
134	2				92			NC	300	106500	3	5	4.25	505	429	5253	5	9	ui	6
136	7	6	84					NC	85	51000	3	4	2	505	252	5253	5	9	ui	6
160	5	11	89					SC	600	210000	3	12.8	10.8	505	426	5000	5	9	ui	6
133	5	6	89					NC	195	71000	3	5.3	4	476	395	4500	5	9	uc	5
23	5	11	87					DE	546	200000	3	13.3	10.5	674	532	5500	5	3	ui	6
166	3			12	92			TN	205	75000	3	4	3.25	505	410	6000	6	9	ui	6
163	5	12	81					TN	180	60000	3	0.5	0.43	505	434	5253	6	9	ui	6
167	5	2	74					TN	950	346750	3	7.3	2.9	505	200	4900	6	9	uc	5
143	5	3	86					OK	1060	346960	3	16.5	14.5	600	530	5000	7	10	u	3
93	2			1	95			NV	712	260000	3	50	40	505	404	5253	8	11	u	3
13	8	11	84	7	91	5	85	CA	100	36500	3	1.54	1.2	505	393	6500	9	13	uc	5
111	5	2	81					NY	720	148000	4	0	0	0	0	5253	2	6	c	1
49	5	9	90					IN	125	32500	4	0	0	0	0	5253	3	1	i	2
161	5	12	89					SD	65	16900	4	0	0	0	0	5253	4	5	c	1
89	5	11	85					MN	50	10000	4	0	0	0	0	5253	4	5	c	1
51	5	10	88					IA	100	25500	4	0	0	0	0	5253	4	5	i	2
78	5	3	87					MN	470	120000	4	0	0	0	0	5253	4	5	ui	6
26	8	4	89			9	89	FL	540	140400	4	0	0	0	0	5253	5	8	i	2
35	3			1	92			FL	660	207000	4	0	0	0	0	5253	5	8	i	2
194	3				91			WV	550	132000	4	0	0	0	0	5253	5	1	i	2
22	5	3	84					DE	600	230000	4	0	0	0	0	5253	5	3	u	3
165	5	10	89					TN	48	12480	4	0	0	0	0	8000	6	9	i	2
168	4	10	90					TN	50	13000	4	0	0	0	0	5253	6	9	i	2
5	4			9	90			AK	200	60000	4	0	0	0	0	5253	9	11	c	1
192	5	7	79					WA	450	117000	4	0	0	0	0	5253	9	11	u	3
4	5	6	81					AK	45	15435	5	0	0	0	0	5253	9	11	c	1

Table 2E-3 shows the reduced the data set, containing only those numbers that are used to calculate *F*, *HR1*, and *MAPCRNR*. A plant in Puerto Rico was eliminated from the data set because Puerto Rico is not modeled in NEMS. The first two columns are the plant number and State, which are used for identification purposes only. The rest of the column headings are the same as the variable names used in the FORTRAN data processing program. The variable names are:

QMSW	=	quantity of MSW in tons/year utilized at the facility
OUTTYP	=	type of energy output, where: 1 = steam only 2 = electricity only 3 = steam and electricity
GR_KWH	=	gross kWh of electricity generated per ton of MSW
NT_KWH	=	net (gross-in-plant use) kWh of electricity generated per ton of MSW
BTU	=	number of Btu per pound of MSW
CR	=	census region in which plant is located
NR	=	NERC region in which plant is located
SNO	=	number representing to which sector(s) energy is output, where: 1 = commercial 2 = industrial 3 = utility

Table 2E-3. Data Set Used as Input to FORTRAN Program that calculates *F*, *HR*, and *MAPCRNR*

		QMSW	OUTTYP	GR_KWH	NT_KWH	BTU	CR	NR	SNO
66	MA	80000	1	0	0	5253	1	7	2
95	NH	36500	1	0	0	5253	1	7	1
112	NY	147000	1	0	0	5253	2	6	1
110	NJ	15600	1	0	0	5253	2	3	2
115	NY	930750	1	0	0	5253	2	6	1
152	PA	14200	1	0	0	4500	2	3	1
116	NY	46500	1	0	0	5253	2	6	2
129	NY	292000	1	0	0	5253	2	6	4
201	WI	51480	1	0	0	5253	3	4	2
48	IN	701830	1	0	0	5253	3	1	3
75	MN	18000	1	0	0	5253	4	5	4
76	MN	6500	1	0	0	5253	4	5	1
81	MN	25000	1	0	0	5253	4	5	2
84	MN	33000	1	0	0	5253	4	5	2
85	MN	22000	1	0	0	5253	4	5	2
88	MN	22440	1	0	0	5253	4	5	2
80	MN	27375	1	0	0	5253	4	5	2
91	MO	10950	1	0	0	5253	4	10	2
77	MN	77000	1	0	0	8000	4	5	2
59	MD	119241	1	0	0	5253	5	3	2
185	VA	23400	1	0	0	5253	5	1	2
30	FL	10296	1	0	0	5253	5	8	2
159	SC	72000	1	0	0	5253	5	9	2
32	FL	9125	1	0	0	5253	5	8	1
178	VA	8400	1	0	0	5253	5	9	2
179	VA	72500	1	0	0	5253	5	9	1
41	GA	175200	1	0	0	5253	5	9	2
182	VA	54750	1	0	0	5253	5	9	2
180	VA	23725	1	0	0	5253	5	9	1
90	MS	37000	1	0	0	5253	6	10	2
1	AL	13000	1	0	0	5253	6	9	2
3	AL	100000	1	0	0	5253	6	9	2
2	AL	221000	1	0	0	5253	6	9	2
164	TN	18250	1	0	0	5253	6	9	2
162	TN	26000	1	0	0	5253	6	9	2
169	TN	62050	1	0	0	5253	6	9	2
175	TX	14736	1	0	0	5253	7	2	2
7	AR	22598	1	0	0	5253	7	10	2
141	OK	19000	1	0	0	5253	7	10	2
8	AR	16200	1	0	0	5253	7	10	2
171	TX	8190	1	0	0	5253	7	2	2
170	TX	13767	1	0	0	5253	7	2	2
174	TX	1872	1	0	0	5253	7	2	1
173	TX	832	1	0	0	5253	7	2	1
92	MT	15000	1	0	0	5253	8	11	3
43	ID	8308	1	0	0	5253	8	11	2
176	UT	127750	1	0	0	5253	8	11	2
188	WA	40150	1	0	0	5253	9	11	2
6	AK	5500	1	0	0	5253	9	11	1
61	MA	465000	2	620	496	5500	1	7	3
68	MA	438000	2	688	550	4500	1	7	3
62	MA	550000	2	642	572	5081	1	7	3
65	MA	435000	2	653	550	5500	1	7	3
64	MA	532500	2	667	600	5000	1	7	3
67	MA	630000	2	659	570	5000	1	7	3
97	NH	155000	2	550	470	5000	1	7	3
96	NH	183960	2	476	425	4500	1	7	3

Table 2E-3. Data Set Used as Input to FORTRAN Program that calculates *F*, *HR*, and *MAPCRNR* (Continued)

		QMSW	OUTTYP	GR_KWH	NT_KWH	BTU	CR	NR	SNO
94	NH	65000	2	440	372	5400	1	7	3
17	CT	624000	2	620	472	5500	1	7	3
157	RE	234000	2	671	543	5200	1	7	3
19	CT	190530	2	585	520	5000	1	7	3
18	CT	131750	2	600	550	4500	1	7	3
16	CT	170638	2	677	560	5300	1	7	3
55	ME	163000	2	500	368	5000	1	7	3
14	CT	720000	2	720	640	5300	1	7	3
186	VT	75000	2	548	470	5253	1	5	3
15	CT	195000	2	620	535	5000	1	7	3
52	ME	64240	2	620	471	5200	1	7	3
53	ME	221555	2	620	564	6200	1	7	3
54	ME	215000	2	545	455	6200	1	7	3
109	NJ	165000	2	475	425	4500	2	3	3
107	NJ	425517	2	535	455	5500	2	3	3
104	NJ	156000	2	542	425	5200	2	3	3
105	NJ	437000	2	670	567	5400	2	3	3
106	NJ	876000	2	530	482	4500	2	3	3
108	NJ	527425	2	620	561	4950	2	3	3
101	NJ	725000	2	501	475	4500	2	3	3
103	NJ	400000	2	753	625	5500	2	3	3
102	NJ	124100	2	620	482	4650	2	3	3
146	PA	834000	2	675	600	5200	2	3	3
147	PA	330000	2	672	560	5000	2	3	3
145	PA	700000	2	620	517	5253	2	3	3
127	NY	328500	2	620	502	5253	2	6	3
132	NY	914000	2	641	570	4500	2	6	3
154	PA	277000	2	460	392	4500	2	3	3
155	PA	465375	2	620	551	5200	2	3	3
153	PA	378000	2	626	540	4500	2	1	3
149	PA	700000	2	665	600	5200	2	3	3
150	PA	155000	2	588	525	5200	2	3	3
119	NY	126000	2	620	525	5500	2	6	3
120	NY	160000	2	532	370	4450	2	6	3
117	NY	253000	2	736	627	6000	2	6	3
113	NY	210000	2	498	410	5000	2	6	3
114	NY	465000	2	620	496	5500	2	6	3
125	NY	310000	2	760	640	6000	2	6	3
126	NY	657000	2	638	590	4800	2	6	3
124	NY	300000	2	620	540	6000	2	6	3
121	NY	165000	2	560	467	5200	2	6	3
122	NY	62050	2	620	413	5000	2	6	3
98	NJ	306600	2	689	482	4500	2	3	3
99	NJ	302500	2	655	560	5000	2	3	3
100	NJ	438000	2	535	455	4500	2	3	3
138	OH	584000	2	568	491	4800	3	1	3
139	OH	93075	2	550	523	5000	3	1	3
74	MI	173740	2	620	525	6000	3	1	3
69	MI	620500	2	741	645	5200	3	1	3
140	OH	225000	2	507	482	5000	3	1	3
200	WI	46500	2	323	263	5000	3	4	3
197	WI	65000	2	620	539	5759	3	4	3
196	WI	56000	2	620	579	5500	3	4	3
46	IL	379746	2	976	800	6100	3	4	3
50	IA	43500	2	620	589	6200	4	5	3
82	MN	365000	2	700	540	5800	4	5	3
79	MN	460500	2	700	608	5500	4	5	3
87	MN	233600	2	633	550	5000	4	5	3

Table 2E-3. Data Set Used as Input to FORTRAN Program that calculates *F*, *HR*, and *MAPCRNR* (Continued)

		QMSW	OUTTYP	GR_KWH	NT_KWH	BTU	CR	NR	SNO
83	MN	400000	2	620	550	5500	4	5	3
28	FL	63250	2	620	571	4500	5	8	3
25	FL	821250	2	676	608	5200	5	8	3
24	FL	430000	2	537	492	4500	5	8	3
27	FL	46538	2	355	300	5000	5	8	3
135	NC	140400	2	680	550	5253	5	9	3
38	FL	624000	2	600	500	4865	5	8	3
34	FL	186642	2	480	432	4600	5	8	3
36	FL	920000	2	478	430	4000	5	8	3
37	FL	821250	2	709	638	5200	5	8	3
39	FL	325945	2	650	550	4800	5	8	3
31	FL	1022000	2	480	388	5000	5	8	3
29	FL	558450	2	670	630	5000	5	8	3
40	FL	306000	2	510	450	5000	5	8	3
33	FL	163000	2	525	362	5000	5	8	3
57	MD	186000	2	620	583	6800	5	3	3
181	VA	985150	2	610	540	4400	5	1	3
58	MD	558450	2	780	644	5500	5	3	3
183	VA	182000	2	620	465	5253	5	9	3
177	VA	338400	2	520	470	4800	5	1	3
172	TX	20400	2	620	476	4500	7	2	3
142	OK	300000	2	620	284	5200	7	10	3
9	CA	110000	2	725	630	5600	9	13	3
187	WA	35000	2	525	350	4500	9	11	3
42	HI	600000	2	550	460	4800	9	13	3
191	WA	248200	2	585	497	5253	9	11	3
10	CA	293000	2	596	450	4750	9	13	3
144	OR	190000	2	536	450	4700	9	11	3
190	WA	54000	2	406	345	4500	9	11	3
11	CA	427000	2	648	540	4800	9	13	3
193	WA	100000	2	620	533	5600	9	11	3
189	WA	803000	2	660	565	5000	9	11	3
12	CA	638000	2	615	540	4900	9	13	3
21	CT	37000	3	150	130	5000	1	7	3
20	CT	138000	3	500	384	4850	1	7	6
60	MA	112500	3	472	390	4200	1	7	3
63	MA	222000	3	505	409	6000	1	7	6
158	RE	238000	3	531	455	4750	1	7	6
130	NY	55000	3	505	275	5253	2	6	6
128	NY	120000	3	320	140	5253	2	6	6
118	NY	78750	3	505	202	5000	2	6	6
123	NY	583900	3	505	303	5253	2	6	6
151	PA	200000	3	781	500	4500	2	1	6
131	NY	70000	3	990	275	5000	2	6	6
148	PA	21716	3	275	130	4500	2	3	2
198	WI	22880	3	150	100	5450	3	4	6
195	WI	29000	3	505	131	4750	3	5	6
47	IN	113867	3	505	428	5253	3	1	3
73	MI	54750	3	454	373	5253	3	1	6
72	MI	70000	3	505	429	4900	3	1	1
71	MI	194000	3	478	410	5350	3	1	5
45	IL	144000	3	507	380	5253	3	4	3
202	WI	219000	3	505	374	5500	3	4	3
44	IL	400000	3	505	374	5253	3	4	6
70	MI	754000	3	505	374	5253	3	1	5
137	OH	265000	3	505	0	4800	3	1	1
199	WI	33600	3	110	85	5000	3	5	5
86	MN	59000	3	293	220	5500	4	5	3

Table 2E-3. Data Set Used as Input to FORTRAN Program that calculates *F*, *HR*, and *MAPCRNR* (Continued)

		QMSW	OUTTYP	GR_KWH	NT_KWH	BTU	CR	NR	SNO
184	VA	364000	3	505	442	5550	5	9	2
56	MD	710500	3	400	350	5100	5	3	3
134	NC	106500	3	505	429	5253	5	9	6
136	NC	51000	3	505	252	5253	5	9	6
160	SC	210000	3	505	426	5000	5	9	6
133	NC	71000	3	476	395	4500	5	9	5
23	DE	200000	3	674	532	5500	5	3	6
166	TN	75000	3	505	410	6000	6	9	6
163	TN	60000	3	505	434	5253	6	9	6
167	TN	346750	3	505	200	4900	6	9	5
143	OK	346960	3	600	530	5000	7	10	3
93	NV	260000	3	505	404	5253	8	11	3
13	CA	36500	3	505	393	6500	9	13	5
111	NY	148000	4	0	0	5253	2	6	1
49	IN	32500	4	0	0	5253	3	1	2
161	SD	16900	4	0	0	5253	4	5	1
89	MN	10000	4	0	0	5253	4	5	1
51	IA	25500	4	0	0	5253	4	5	2
78	MN	120000	4	0	0	5253	4	5	6
26	FL	140400	4	0	0	5253	5	8	2
35	FL	207000	4	0	0	5253	5	8	2
194	WV	132000	4	0	0	5253	5	1	2
22	DE	230000	4	0	0	5253	5	3	3
165	TN	12480	4	0	0	8000	6	9	2
168	TN	13000	4	0	0	5253	6	9	2
5	AK	60000	4	0	0	5253	9	11	1
192	WA	117000	4	0	0	5253	9	11	3
4	AK	15435	5	0	0	5253	9	11	1

The FORTRAN program that determines F, HR, and MAPCRNR is listed below:

```
C MSWGD1.FOR  *   CALCULATES F,MAPCRNR,MAPNRCR,HR,ERATIO
C
C  TQME= Total Quantity of MSW in electricity only use
C  TEM = total quantity of electricity from MSW
      DIMENSION TQ(3,9,3),TCRNR(9,13),SUMTCR(9),SUMTQ(9),F(3,10,3),
     * SUMTNR(13),QMSW(205),OUTTYP(205),GR_KWH(205),SNO(205),CR(205),
     * BTU(205),SFACT(3,6)
      REAL NT_KWH(205),NR(205),MAPCRNR(9,13),MAPNRCR(9,13)
      INTEGER S,SN,U,RN,RC
C
      CHARACTER*1 FILL
      DATA SFACT/1,0,0,.5,.5,0, 0,1,0,.5,0,.5, 0,0,1,0,.5,.5/
      DATA TQME/0./,TEM/0./,TQ/81*0./TCRNR/117*0./MAPCRNR/117*0./
      DATA SUMTQ/9*0./,I/1/,MAPNRCR/117*0./,SUMTCR/9*0./,SUMTNR/13*0./
C
      OPEN (4,FILE='MSWGD1.DAT',STATUS='OLD')
      OPEN (6,FILE='OUT.DAT',STATUS='OLD')
C
      WRITE(6,104)SFACT(1,4)
104   FORMAT(F3.1)
C
      READ(4,99)FILL
99    FORMAT(A1)
1     READ(4,101,END=2)QMSW(I),OUTTYP(I),GR_KWH(I),NT_KWH(I),BTU(I),
     *  CR(I),NR(I),SNO(I)
101   FORMAT(14X,F7.0,F8.0,F11.0,F11.0,F8.0,3F3.0)
```

The FORTRAN program that determines F, HR, and MAPCRNR (Continued)

```
      I=I+1
      GO TO 1
C
2     IF=I-1
      WRITE(6,102)
      WRITE(6,103) IF
102   FORMAT(' READ FINISH')
      DO 5 I=1,IF
      IF (OUTTYP(I).NE.2) GO TO 5
      TQME=TQME+QMSW(I)*BTU(I)*2000.
      TEM=TEM+QMSW(I)*GR_KWH(I)*3412.
5     CONTINUE
      WRITE(6,103)2
103   FORMAT(' PROCESSED ',I3)
C
      ERATIO=TQME/TEM
C
      DO 8 I=1,IF
      IF (OUTTYP(I).EQ.1) GO TO 6
      IF (OUTTYP(I).LT.4) GO TO 8
      IF (OUTTYP(I).GT.5) GO TO 8
6     RC=CR(I)
      J=SNO(I)
      DO 7 S=1,3
7     TQ(3,RC,S)=TQ(3,RC,S)+QMSW(I)*BTU(I)*2000.*SFACT(S,J)
8     CONTINUE
      WRITE(6,103) 1
C
      DO 11 I=1,IF
      IF (OUTTYP(I).NE.2) GO TO 11
      RC=CR(I)
      N1=NR(I)
      J=SNO(I)
      TCRNR(RC,N1)=TCRNR(RC,N1)+QMSW(I)*BTU(I)*2000.*GR_KWH(I)
      DO 10 S=1,3
      TQ(1,RC,S)=TQ(1,RC,S)+QMSW(I)*BTU(I)*2000.*SFACT(J,S)*
     *    (NT_KWH(I)/GR_KWH(I))
      TQ(2,RC,S)=TQ(2,RC,S)+QMSW(I)*BTU(I)*2000.*SFACT(J,S)*
     *    (1.-NT_KWH(I)/GR_KWH(I))
10    CONTINUE
11    CONTINUE
      WRITE(6,103) 2
C
      DO 13 I=1,IF
      IF (OUTTYP(I).NE.3) GO TO 13
C  /* STEAM & ELECTRICITY   */
      RC=CR(I)
      N1=NR(I)
      J=SNO(I)
      TCRNR(RC,N1)=TCRNR(RC,N1)+QMSW(I)*BTU(I)*2000.*GR_KWH(I)
      IF (J.LE.4) THEN
      DO 12 S=1,3
      TQ(1,RC,S)=TQ(1,RC,S)+QMSW(I)*NT_KWH(I)*3412.*ERATIO*SFACT(S,J)
      TQ(2,RC,S)=TQ(2,RC,S)+QMSW(I)*(GR_KWH(I)-NT_KWH(I))*3412.*
     *    ERATIO*SFACT(S,J)
      TQ(3,RC,S)=TQ(3,RC,S)+QMSW(I)*(BTU(I)*2000.-GR_KWH(I)*3412.*
     *    ERATIO)*SFACT(S,J)
12    CONTINUE
C  /* FOR COGEN WITH MULTIPLE USE, ALLOCATE STEAM TO COMMERCIAL OR
C     INDUSTRIAL & ELECTRICITY TO UTILITY  */
      ELSE
      TQ(1,RC,3)=TQ(1,RC,3)+QMSW(I)*NT_KWH(I)*3412*ERATIO
      TQ(2,RC,3)=TQ(2,RC,3)+QMSW(I)*(GR_KWH(I)-NT_KWH(I))*3412
C  /* IF J=5 THEN STEAM TO COMMERCIAL, J=6 THEN STEAM TO INDUSTRIAL */
      TQ(3,RC,J-4)=TQ(3,RC,J-4)+QMSW(I)*(BTU(I)*2000.-GR_KWH(I)*
     *             3412*ERATIO)
      ENDIF
```

The FORTRAN program that determines F, HR, and MAPCRNR (Continued)

```
13    CONTINUE
      WRITE(6,103) 3
C
      DO 15 RC=1,9
      DO 15 RN=1,13
15    SUMTCR(RC)=SUMTCR(RC)+TCRNR(RC,RN)
      WRITE(6,111)
111   FORMAT(' SUMTCR ...')
      WRITE(6,112)SUMTCR
112   FORMAT(1X,9E12.5)
C
      DO 16 RC=1,9
      DO 16 RN=1,13
16    MAPCRNR(RC,RN)=TCRNR(RC,RN)/SUMTCR(RC)
      WRITE(6,103) 4
C
      DO 20 RN=1,13
      DO 20 RC=1,9
20    SUMTNR(RN)=SUMTNR(RN)+TCRNR(RC,RN)
      WRITE(6,110)
110   FORMAT(' SUMTNR ...')
      WRITE(6,112)SUMTNR
C
      DO 25 RN=1,13
      DO 25 RC=1,9
      IF (SUMTNR(RN).LT.0.00001) GO TO 21
      MAPNRCR(RC,RN)=TCRNR(RC,RN)/SUMTNR(RN)
      GO TO 25
21    MAPNRCR(RC,RN)=0.
25    CONTINUE
      WRITE(6,103) 5
C
C.. calc maping for nr to cr. calc sumtnr, cal mapnrcr=tcrnr/sumtnr
C  need both mapping arrays in MSW code.
C
      DO 19 RN=1,13
19    WRITE(6,107)(MAPCRNR(RC,RN),RC=1,9)
107   FORMAT(1X,9F7.4)
C
      WRITE(6,99)
      DO 22 RN=1,13
22    WRITE(6,107)(MAPNRCR(RC,RN),RC=1,9)
C
      DO 17 RC=1,9
      DO 17 S=1,3
      DO 17 U=1,3
17    SUMTQ(RC)=SUMTQ(RC)+TQ(U,RC,S)
C
      DO 18 RC=1,9
      DO 18 S=1,3
      DO 18 U=1,3
18    F(U,RC,S)=TQ(U,RC,S)/SUMTQ(RC)
C
C  F MATRIX OUTPUT, EACH COLUMN: U(1), U(2), U(3)
C    EACH GROUP OF 3 ROWS IS A CENSUS REGION
C    EACH OF THE 3 ROWS ARE SECTORS: S(1), S(2), S(3)
      DO 26 RC=1,9
      DO 26 S=1,3
26    WRITE(6,107)(F(U,RC,S),U=1,3)
C
      HR=ERATIO*3412.
      WRITE(6,105)
105   FORMAT(//,'    ERATIO        HR')
      WRITE(6,106)ERATIO,HR
106   FORMAT(2E12.6,//)
      STOP
      END
```

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1. Municipal Solid Waste Submodule Flowchart 14

3. Wind Energy Submodule (WES)

Model Purpose

The objective of the Wind Energy Submodule (WES) is to project the cost, performance, and availability of wind-generated electricity, and provide this information to the Electricity Capacity Planning (ECP) component of the Electric Market Module (EMM) for the building of new capacity in competition with other sources of electricity generation.

Projections are based on the performance of a "mix" of horizontal axis wind turbines (HAWTs) that have been installed and are currently operational.

The version of NEMS used in *AEO95* accounts for only grid-connected electricity generation. It does not consider dispersed, remote or any non-grid-connected applications. For wind, the grid connection or transmission costs are accounted for by the EMM, in the same manner as fossil generation technologies which may be less sensitive to siting, therefore understating these costs as pertains to wind.

The EMM provides to the WES information on installed wind capacity after convergence is reached. WES then calculates the remaining wind resources available for future installations. This accounting of remaining resources is needed since wind energy consists of limited quantities of high-quality resources that are depleted as turbines are installed on windy sites.

Relationship of the Wind Submodule to Other Models

As a submodule of the Renewable Fuels Module (RFM), WES provides its output through, and receives data through, the RFM. WES is initiated by a call from the RFM. The RFM then provides input to and receives data from the EMM.

The WES model calculates values for two variable arrays, which are then passed to the EMM for further processing. The calculated arrays are (1) yearly available capacity per wind class per region, and (2) yearly capacity factors for each wind class, region, and subperiod (i.e., "slice" of the load duration curve). The first array is calculated from the available land area versus wind class (average speed "bins"), the energy per unit swept rotor area, and the annual capacity factor. The second array is calculated from the subperiod energy percentages and subperiod definitions. All other input data are passed directly to the EMM. The model generates a supply curve with a straightforward (deterministic) calculation from wind turbine performance projections. The uncertainties in the results are related to the technological cost and performance projections and the assumptions about the availability of wind.

Modeling Rationale

Theoretical Approach

The most important task of the WES is to produce energy supply curves from wind resource and wind turbine cost/performance data. This is accomplished by calculating, for three wind classes, the maximum conceivable turbine capacity that could be installed, given the available land area, wind resource, and the current year's turbine capacity factor.

Resource quality data and the yearly capacity factor are used to calculate wind farm performance data on a sub-yearly level, as required by the EMM. Calculations are made for each time slice, wind class, and region.

Substantial commercial wind installations have existed since the early 1980's. Counts of these pre-existing installations are used to adjust figures on available windy land at the beginning of the NEMS model run. The WES tracks the quantity of windy land remaining by wind class that is available for future development after each run year by calculating the amount of resource required to provide a given amount of wind installed capacity and subtracting that amount from the total resource available. This assumes that the highest quality resource (as measured by average wind speed) is used first. These wind classes are represented by specific capacity factors for each region which correspond to time of day and season. The amount of resource used is then subtracted from the previous year's available amount to yield the current year's available windy land. A sample output for a given regional availability would be 50 MW of Class 1 resource, 150 MW of Class 2, and 400 MW of Class 3.

Fundamental Assumptions

WES Quantity Projections

The EMM requires capacity, performance, and cost data on the basis of NERC Regions. WES provides data by NERC Region based on 13 NERC Regions/Subregions with Alaska and Hawaii separated out, and not included in wind resources given to EMM.

Since horizontal-axis wind turbines are the predominant type in U.S. installations, accounting for over 95 percent of U.S. generating capacity, only this type is represented in the WES. No significant increase in accuracy or detail would be achieved by including vertical-axis designs as well. The most current, comprehensive and accurate knowledge exists for the horizontal types and there are limitations on the detail with which projections of cost and performance can be made. For a regional model, the appropriate level of detail assumes a hybrid of various horizontal-axis turbines.

Land Use Estimates

It is assumed that wind turbines are installed in a grid pattern with spacing between them equal to five times the rotor diameter in one direction and ten times the rotor diameter in the other direction.

Dispersed Penetration

It is assumed that penetration of dispersed wind energy systems will not impact the "learning curve" cost and performance changes of wind energy systems for central power generation. The two types of technologies are different in scale and therefore the learning in one is not applicable to the other.

Projected Btu Value of Wind Energy

Energy balance computations and report writing and consumption rates within NEMS require a heat rate, i.e., an equivalent fossil-fuel displacement for wind generated electricity. This is currently set at the heat rate for fossil-fueled steam-electric plants of 10,302.

Alternative Approaches

In most national-level energy models, wind technologies have not been considered on an equivalent basis with other sources of electricity generation. The few models that have are the Electric Power Research Institute's (EPRI) Electric Generation Expansion Analysis System (EGEAS) and the Environmental Defense Fund's (EDF) "Elfin". Also, DOE's Wind/Hydro/ Ocean Division has developed spreadsheet models that project utility market penetration of wind technologies based on comparisons of wind plant costs of energy (COE's) and marginal COE's for conventional generators.

EGEAS was developed jointly by EPRI and Stone and Webster. It consists of a set of computer programs for utility system planners which determines an optimal expansion plan or simulates a pre-specified plan. Expansion plans define the type, size, and installation date for each new generating facility. The objective is to find an expansion plan which minimizes the sum of operating expenses and capital fixed charges. EGEAS provides three main optimization techniques which offer a balance between modeling flexibility and computational efficiency. EGEAS can handle a wide range of dispatchable and nondispatchable technologies, including wind.

The limitation of EGEAS with regard to renewables is that the variability or intermittency of wind resources is not explicitly incorporated into the model but rather is treated as a deterministic negative load, (e.g., as an hourly time series of power outputs over a year) and simply subtracted from utility demand. Therefore, wind is not explicitly competed or dispatched against other energy forms on an equal basis.

The ELFIN model from EDF, which stands for Electric Utility Financial and Production Cost Model, is a probabilistic model which simulates electric-system dispatch in order to calculate expected cost of operation. It has been used most extensively in utility rate hearings before state energy commissions. Elfin can also be used to choose the optimal expansion plan for a utility based on annual present-value of system costs and benefits. No attempt is made to compare life-cycle costs and benefits. Elfin's outputs include the generating level of each plant, per week, and year, fixed and variable costs, fuel usage, and emissions. Reliability is measured by loss-of-load probability (LOLP) and is displayed in days per year.

The DOE Wind/Hydro/Ocean Division's Model projects the growth of the U.S. electric utility market for wind turbines on a regional basis. Market share to the year 2030 is allocated on the basis of financial attractiveness, market acceptance of the technology, plant types and capacities, coincidence of utility load and wind power curves, wind resource limitations, and limitations on wind penetration into regional power pools.

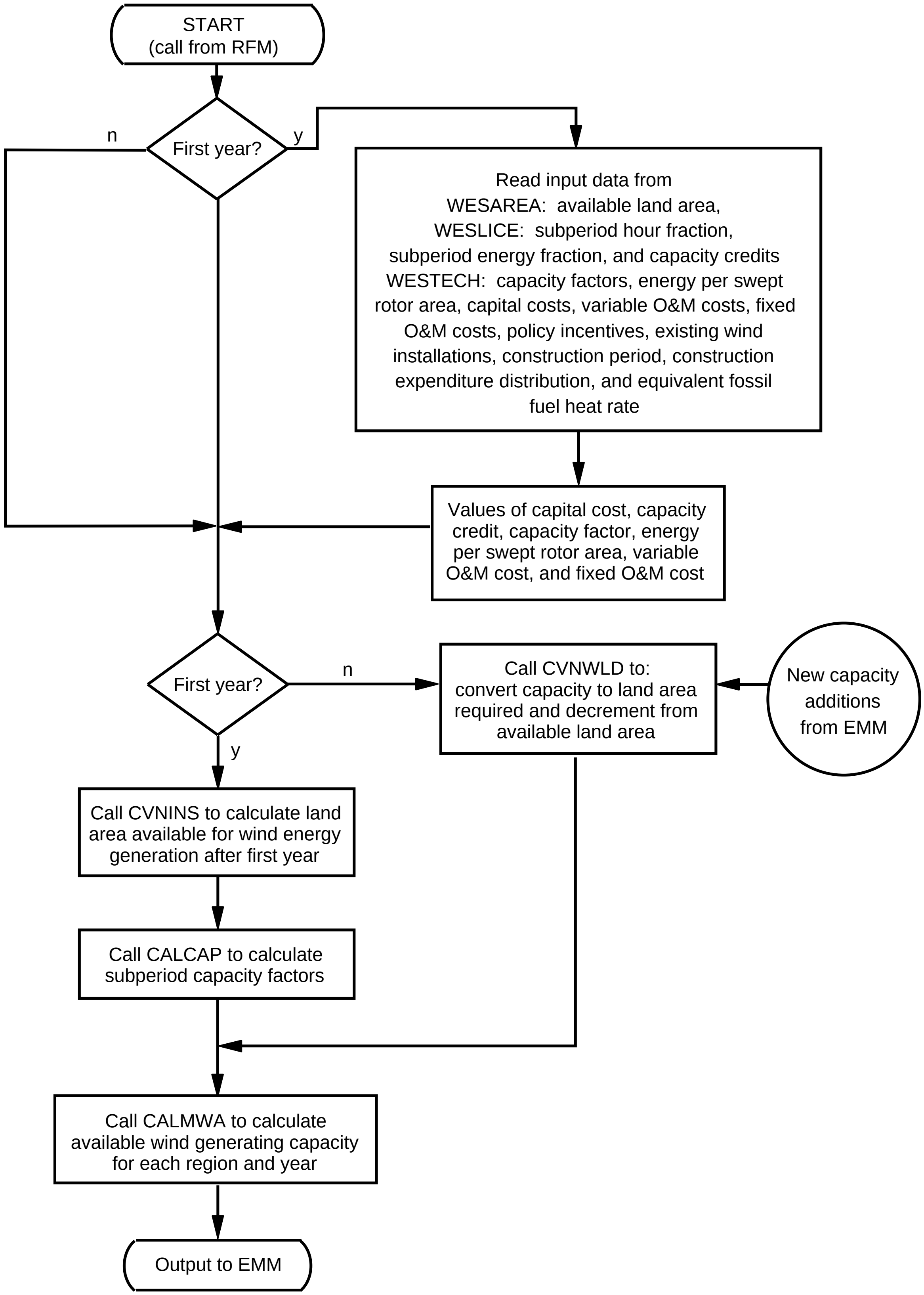
The model is built around concepts of new product diffusion into the marketplace. It is a spreadsheet-based tool that estimates market capture in competition with conventional fossil fuel-fired generating plants on a regional basis. It expands on previous techniques by incorporating a market acceptance factor based on ratios of levelized costs of energy for conventional plants and wind turbines (benefit cost ratios). Although sensitivities to fuel costs and mixes can be evaluated with this model, nonfinancial, political factors cannot be incorporated so it is of limited usefulness for other purposes such as policy analyses.

Wind Energy Submodule Structure

Submodule Flow Diagram

A flow diagram showing the main computational steps and relationships of the Wind Energy Submodule is shown in Figure 2.

Figure 2. Wind Energy Submodule Flowchart



Key Computations and Equations

Some of the input data are at 5-year intervals. The first calculation performs a linear interpolation on these data to calculate yearly values.

For the first year, subroutine CVINS is called to calculate the land area remaining for wind energy development, after deducting from the total windy land area available that needed to generate the existing installed capacity. This calculation is performed for each wind class, with capacity assigned first to wind class 1 land area, followed by wind class 2 land area when the wind class 1 land area is completely used, and then similarly to wind class 3 land area. The calculation assumes a turbine spacing of 5D x 10D, where D is the diameter of the turbine rotor.

Following the calculation of land area used by pre-existing wind generating capacity, subroutine CALCAP is called to calculate the capacity factor for each region, year, and subperiod (time slice).

For all years after the first year, subroutine CVNWLD is then called to calculate the land area remaining for wind energy development, after deducting from the previously remaining land area available the land area needed for the amount of wind generating capacity installed in the previous year. This calculation is performed for each wind class, with capacity assigned first to wind class 1 land area, followed by wind class 2 land area when the wind class 1 land area is completely used, and then similarly to wind class 3 land area. The calculation assumes a turbine spacing of 5D x 10D, where D is the diameter of the turbine rotor.

Subroutine CALMWA is then called to convert the land area available for wind generation development to the swept rotor area needed to fully develop the available land area. The calculation assumes a turbine spacing of 5D x 10D, where D is the diameter of the turbine rotor. This swept rotor area is then converted to the amount of wind energy generation capacity available in each region for each year and each wind class.

Appendix 3-A: Inventory of Variables, Data, and Parameters

This Appendix describes the variables, parameter estimates, and data inputs associated with the Wind Energy Submodule. Table 3A-1 provides a tabular listing of model variables and parameters. The table contains columns with information on item definitions, modeling dimensions, data sources, measurement units, and documentation page references.

The remainder of Appendix 3-A consists of detailed descriptions of data inputs and variables, including discussions on supporting data assumptions and transformations.

Table 3A-1. NEMS Wind Energy Submodule Inputs and Outputs

Model Variable	Definition and Dimensions	Source	Units	Page Reference
INPUT DATA				
CAPCOS	Installed capital cost of wind generation in NERC Region *n* in year *y*.	EPRI TAG™, 1993.	$/kW	74
CFANN	Annual wind capacity factor for wind class *w* in year *y*.	SAIC, 1990.	Unitless	74
CREDIT	Wind capacity credit for NERC Region *n* in year *y*.	Determined within EMM.	Unitless	75
ENAREA	Energy per swept rotor area for wind class *w* in year *y*.	SAIC, 1990.	kWh/m^2	75
EXWIND	Pre-existing total wind electric capacity installed in NERC Region *n* through year *y*.	DOE Wind Program records.	MW	76
HEAT	Fossil fuel equivalent heat rate for wind.	EIA, 1992.	Btu/kWh	76
*LEAD**	Construction lead time.	EPRI TAG™ + 1 year.	Years	76
OMFCOS	Fixed O&M cost for NERC Region *n* in year *y*.	EPRI TAG™, 1993.	$/kW	77
OMVCOS	Variable O&M cost for NERC Region *n* in year *y*.	EPRI TAG™, 1993.	mills/kWh	77
PERCON	Fraction of construction completed in each year of construction.	EPRI TAG™, 1993.	Unitless	77
POLICY	Policy incentives for NERC Region *n* in year *y*.	Energy Policy Act of 1992.	mills/kWh	77
SLICE	Hour fraction for subperiod *l* in NERC Region *n*.	WNDSLICE preprocessing program (PERI).	Unitless	78

Table 3A-1. NEMS Wind Energy Submodule Inputs and Outputs (Continued)

Model Variable	Definition and Dimensions	Source	Units	Page Reference
STAREA	Land area available for wind plant development in NERC Region *n* and wind class *w*.	Elliot 1991.	sq. km	78
SUBPER	Energy fraction for subperiod *l* in NERC Region *n*.	WNDSLICE preprocessing program (PERI).	Unitless	79
UCAPWNU	Total utility grid-connected wind electric capacity installed in NERC Region *n* through year *y*.	EMM output variable in UDATOUT COMMON block.	GW	79
UCAPWNN	Total nonutility grid-connected wind electric capacity installed in NERC Region *n* through year *y*.	EMM output variable in UDATOUT COMMON block.	GW	79
CALCULATED VARIABLE				
AREA	Energy per unit swept rotor area for wind class *w* in year *y*.	*ENAREA*, and interpolation for intermediate years.	kWh/m^2	81, 83, 85
CF	Annual capacity factor for wind class *w* in year *y*.	*CFANN*, and interpolation for intermediate years.	Unitless	81, 83, 85
LDAREA	Land area remaining for wind plant development in NERC Region *n* after year *y* for wind class *w*.		sq. km	82, 83, 84
LDUSED	Land area needed to supply wind generating capacity in NERC Region *n* in year *y*, by wind class *1*.		sq. km	81, 83
LDPLUS	Land area needed to supply wind generating capacity in NERC Region *n* in year *y*, by wind class *2* or *3*.		sq. km	82, 83, 84
SWAREA	Swept rotor area available for wind class w in NERC Region n in year y, m^2.		sq. km	85
WSCWIEL	Available capacity in NERC Region *n*, wind class *w* and year *y*.	RFM output variable in WRENEW COMMON block.	MW	85
*WCCWIEL***	Wind plant capital cost for NERC Region *n* in year *y*.	*CAPCOS*, and interpolation for intermediate years. RFM output variable in WRENEW COMMON block.	$/kW	—
*WCRWIEL***	Capacity credit for NERC Region *n* in year *y*.	*CREDIT*, and interpolation for intermediate years. RFM output variable in WRENEW COMMON block.	Unitless	—

Table 3A-1. NEMS Wind Energy Submodule Inputs and Outputs (Continued)

Model Variable	Definition and Dimensions	Source	Units	Page Reference
WSFWIEL	Capacity factor for NERC Region *n* in year *y*, wind class *w*, and subperiod *l*.	RFM output variable in WRENEW COMMON block.	Unitless	84
*WHRWIEL***	Equivalent heat rate for wind in NERC Region *n* in year *y*.	*HEAT*. RFM output variable in WRENEW COMMON block.	Btu/kWh	—
*WCLT(9)***	Construction lead time for wind.	*LEAD*. RFM output variable in WRENEW COMMON block.	Years	—
*WOCWIEL***	Fixed O&M costs for NERC Region *n* in year *y*.	*OMFCOS*, and interpolation for intermediate years. RFM output variable in WRENEW COMMON block.	$/MW	—
*WCPC(9,y)***	Fraction of construction for wind completed in year *y*.	*PERCON*. RFM output variable in WRENEW COMMON block.	Unitless	—
*WCSU(9,y)***	Policy incentives for wind in year *y*.	*POLICY(1,y)*. RFM output variable in WRENEW COMMON block.	mills/kWh	—
*WVCWIEL***	Variable O&M costs for NERC Region *n* in year *y*.	*OMVCOS*, and interpolation for intermediate years. RFM output variable in WRENEW COMMON block.	mills/kWh	—

*Three years is minimum build time allowed for *AEO95*.
**Intermediate values, linearly interpolated from the source variable.

MODEL INPUT: *CAPCOS*

DEFINITION: Installed capital cost of wind generation in NERC Region *n* in year *y* at 5-year intervals; ($/kW).

Values of capital cost are read into the WES from the WESTECH data file. This value is passed to EMM and represents a capital cost after all learning has taken place exclusive of contingencies and is deflated to 1987 dollars. This value is $690.

SOURCE: Electric Power Research Institute, *TAG™ — Technical Assessment Guide*, 1993.

MODEL INPUT: *CFANN*

DEFINITION: Annual wind capacity factor for wind class *w* in year *y*; (Unitless).

Current performance estimates are based on a composite analysis of commercial turbines. Performance data are based on expert judgment projected for 5-year intervals. Specifically, 1995 data are based on the improvements expected from a turbine similar in technological development to the U.S. Windpower 33M-VS. For the years 2000 and 2005, data are based on the improvements expected as a result of the DOE Wind Energy Program R&D, with improvements built up on a subsystem level. Beyond 2005 there is a higher degree of uncertainty regarding technology advances, so small incremental improvements are assumed.

Performance projections are taken from the accelerated federal wind technology R&D funding scenario used in the 1990 National Energy Strategy technology characterizations. Because the characterizations termed "accelerated" in 1990 assumed a funding level for the Federal R&D Program that closely duplicates the prevailing levels, and because of cooperative programs with industry and utilities, the 1990 accelerated scenario is representative of actual technology development.

SOURCES: Science Applications International Corporation, "Renewable Energy Technology Characterizations," Report in support of the National Energy Strategy for the U.S. Department of Energy, Office of Conservation and Renewable Energy, October 1990.

Science Applications International Corporation, "Renewable Energy Technology Evolution Rationales," Report in support of the National Energy Strategy for the U.S. Department of Energy, Office of Conservation and Renewable Energy, October 1990.

MODEL INPUT: *CREDIT*

DEFINITION: Wind capacity credit for NERC Region *n* in year *y* at 5-year intervals; (Unitless).

The Load Capacity Credit (LCC) or capacity value that can be attributed to intermittent generators is a debated issue. The percentage of rated power output for a wind generator that can be considered as firm capacity is dependent on the estimated change the generator effects in a specific utility system's loss-of-load probability (LOLP), generating mix, spinning reserve requirements, and other factors. Values of capacity credit are read into the WES from the WESTECH data file. This file currently assigns a value of zero to the capacity credit for all wind classes and all years. However, a value equal to three quarters of the capacity factor in the peak time period is assigned to the capacity factor in the Electric Capacity Planning Submodule of the EMM.

SOURCE: Value determined by EMM.

MODEL INPUT: *ENAREA*

DEFINITION: Energy per swept rotor area for wind class *w* in year *y*; (kWh/m^2).

Current performance estimates are based on a composite analysis of commercial turbines. Projected performance data are based on the "best knowledge" available at 5-year intervals. Specifically, 1995 data are based on the improvements expected from a turbine similar in technological development to the U.S. Windpower 33M-VS turbine. For the years 2000 and 2005, projections are based on the improvements expected as a result of the DOE Wind Energy Program R&D, with improvements built up on a subsystem level. Beyond 2005 there is a higher degree of uncertainty regarding technology advances, and smaller incremental improvements are assumed.

Performance projections are taken from the accelerated federal wind technology R&D funding scenario used in the 1990 National Energy Strategy technology characterizations. Because the characterizations termed "accelerated" in 1990 assumed a funding level for the Federal R&D Program that closely duplicates the prevailing levels, and because of cooperative programs with industry and utilities, the 1990 accelerated scenario is representative of actual technology development.

SOURCES: Science Applications International Corporation, "Renewable Energy Technology Characterizations," Report in support of the National Energy Strategy for the U.S. Department of Energy, Office of Conservation and Renewable Energy, October 1990.

Science Applications International Corporation, "Renewable Energy Technology Evolution Rationales," Report in support of the National Energy Strategy for the

U.S. Department of Energy, Office of Conservation and Renewable Energy, October 1990.

MODEL INPUT: *EXWIND*

DEFINITION: Pre-existing total wind electric capacity installed in NERC Region *n* through year *y*; (MW).

Substantial commercial wind installations have existed since the early 1980's. Counts of these pre-existing installations are stored in the input data file. These numbers are used to adjust figures on available windy land at the beginning of the NEMS model run.

SOURCE: DOE Wind Program records as maintained by Princeton Economic Research Inc. with data obtained from California Energy Commission, American Wind Energy Association, Pacific Gas and Electric, Southern California Edison, Sand Diego Gas and Electric, and other sources.

MODEL INPUT: *HEAT*

DEFINITION: Fossil fuel equivalent heat rate for wind in NERC region n in year y in 5-year intervals, (Btu/kWh).

This variable is not currently being used by the EMM. An equivalent fossil fuel displacement value of 10,335 Btu/kWh has been assigned, based on EIA data for 1992.

SOURCE: Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91), June 1992.

MODEL INPUT: *LEAD*

DEFINITION: Construction lead time at 5-year intervals; (Years).

The construction period for a wind generating station is currently set at 3, which is the minimum lead time allowed in the EMM.

SOURCE: Electric Power Research Institute, *TAG™ — Technical Assessment Guide*, 1993.

MODEL INPUT: *OMFCOS*

DEFINITION: Fixed O&M costs for NERC Region *n* in year *y* at 5-year intervals; ($/kW).

Values of fixed O&M costs are read into the WES from the WESTECH data file. Fixed O&M costs are currently set in at $20.86/kW (1987 dollars) for all years and all regions, based on the 1993 TAG™.

SOURCE: Electric Power Research Institute, *TAG™—Technical Assessment Guide*, 1993.

MODEL INPUT: *OMVCOS*

DEFINITION: Variable O&M costs for NERC Region *n* in year *y* at 5-year intervals; (mills/kWh).

The variable O&M costs are currently set at zero for all years and all regions based on the 1993 TAG™.

SOURCE: Electric Power Research Institute, *TAG™—Technical Assessment Guide*, 1993.

MODEL INPUT: *PERCON*

DEFINITION: Fraction of construction completed in each year of construction at 5-year intervals; (Unitless).

The construction period for a wind generating station is currently set at 3 years. The construction fraction is set at 0, 10 percent, and 99 percent, respectively.

SOURCE: Electric Power Research Institute, *TAG™—Technical Assessment Guide*, 1993.

MODEL INPUT: *POLICY*

DEFINITION: Policy incentives for NERC Region *n* in year *y* at 5-year intervals; (mills/kWh).

Any production incentives or other adjustments to the cost of wind energy are accounted for in the POLICY variable. Currently, a value of 15 mills per kilowatt hour for the years 1994 through 2003 and zero for all other years is assigned for all regions. This is based on the policy incentive provision of the Energy Policy Act of 1992.

SOURCE: Energy Policy Act of 1992 (Public Law 102-486), Section 1212.

MODEL INPUT: *SLICE*

DEFINITION: Hour fraction for subperiod *l* in NERC Region *n*; (Unitless).

Data for 20 subperiods of the year are provided. The EMM maps the data for these 20 subperiods into nine subperiods used in the EMM and other NEMS modules.

SOURCE: Princeton Economic Research Incorporated (PERI), WNDSLICE preprocessor program, Bertrand L. Johnson.

MODEL INPUT: *STAREA*

DEFINITION: Land area available for wind plant development in NERC Region *n* and wind class *w*; (sq. km).

The land area available for wind plant development has been extracted from data produced at Battelle Pacific Northwest Laboratory (PNL) in support of DOE's National Energy Strategy. In producing the Wind Energy Resource Atlas, PNL staff attempted to account for variations in such factors as anemometer height and placement through measures such as making determinations regarding the validity of data and extrapolating the wind speeds to a standard height.

PNL developed their areal assessments of available resource by breaking down their wind resource maps into one-third degree longitude by one-quarter degree latitude grids. These grid cells formed the basic unit for which wind power and land availability were estimated. Because of resolution limitations, details of wind resource were lost, particularly in mountainous and coastal areas. Since wind speed estimates in mountainous regions apply only to those areas free of obstructions, only a fraction of the ares shown in the Atlas are actually available for development. These fractions were estimated by PNL when producing areal estimates.

PNL developed scenarios covering a range of land exclusion amounts. The WES input data are based on the "moderate" exclusion scenario, which excludes all environmentally protected lands (such as parks and wilderness areas), all urban lands, all wetlands, 50 percent of forest lands, 30 percent of agricultural lands, and 10 percent of range and barren lands. Only land areas with average wind speeds above 12.5 mph are included in the WES input data. Land areas are separated into three classes, depending on the range of average wind speeds. WES class 1 is for average wind speeds above 14.3 mph, class 2 is for average wind speeds from 13.4 mph to 14.3 mph, and class 3 is for average wind speeds from 12.5 mph to 13.4 mph, all at a height of 10 meters.

SOURCES: Elliott, D.L., et al, "An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States," Pacific Northwest Laboratory; Report #PNL-7789, August 1991.

Elliott, D.L., et al, "Wind Energy Resource Atlas" (12 volumes), Pacific Northwest Laboratory, Report PNL-3195; 1980.

MODEL INPUT: *SUBPER*

DEFINITION: Energy fraction for subperiod *l* in NERC Region *n*; (Unitless).

Values were calculated using WNDSLICE, a preprocessing program developed by Princeton Economic Research Incorporated. WNDSLICE uses established NEMS subperiod definitions, daily and seasonal wind resource data, and a synthetic wind turbine power curve to estimate the fraction of the annual wind energy production that falls within the various subperiods.

SOURCE: Princeton Economic Research Incorporated, WNDSLICE preprocessor program.

MODEL INPUT: *UCAPWNN*

DEFINITION: Total nonutility grid-connected wind electric capacity installed in NERC Region *n* through year *y*; (GW).

SOURCE: EMM output variable in UDATOUT COMMON block.

MODEL INPUT: *UCAPWNU*

DEFINITION: Total utility grid-connected wind electric capacity installed in NERC Region *n* through year *y*; (GW).

SOURCE: EMM output variable in UDATOUT COMMON block.

Appendix 3-B: Mathematical Description

This Appendix provides the detailed mathematical specification of the Wind Energy Submodule as presented in the RFM FORTRAN code execution sequence. Subscript definitions are also as they appear in the FORTRAN code.

Subroutine CVNINS (used only for first year)

Equation 3B-1 calculates the land area (in sq. km) needed to supply a particular amount of wind generating capacity in a particular NERC Region, year and wind class:

$$LDUSED_{n,1,w} = \frac{EXWIND_{n,1} \ x \ CF_{1,w} \ x \ 8760 \ x \ \alpha^{sp}}{AREA_{1,w} \ x \ \frac{\pi}{4}} \ x \ C_{conv} \qquad \textbf{(3B-1)}$$

where:

$LDUSED_{n,1,w}$ = Land area needed to supply pre-existing wind generating capacity in NERC Region n in year 1, by wind class w, sq. km,

$EXWIND_{n,1}$ = Pre-existing total wind electric capacity installed in NERC Region n through year 1, MW,

$CF_{1,w}$ = Annual capacity factor for wind class w in year 1,

$AREA_{1,w}$ = Energy per unit swept area for wind class w in year 1, kWh/m^2,

π = 3.141593,

α^{sp} = Scalar derived from 5D x 10D grid spacing of wind generator (α^{sp} = 50),

C_{conv} = Conversion factor $\left(\frac{MW \ x \ h}{\frac{kWh}{m^2}}\right) = 10^{-3}(km^2)$

Equations 3B-2 and 3B-3 calculate the remaining windy land area available for development for wind class w:

If $LDUSED_{n,1,w} < STAREA_{n,w}$, then

$$LDAREA_{n,1,w} = STAREA_{n,w} - LDUSED_{n,1,w}$$
$$LDPLUS_{n,1,w+1} = 0.0 \qquad \textbf{(3B-2)}$$

If $LDUSED_{n,1,w} \geq STAREA_{n,w}$, then

$$LDAREA_{n,1,w} = 0.0$$
$$LDPLUS_{n,1,2} = \left[\frac{AREA_{1,1}}{AREA_{1,2}}\right] x \left[\frac{CF_{1,2}}{CF_{1,1}}\right] x \ (LDUSED_{n,1,1} - STAREA_{n,1}) \qquad \textbf{(3B-3)}$$

where:

$LDAREA_{n,1,w}$	=	Wind class *w* land area available for development in NERC Region *n* after year *1*, sq. km,
$STAREA_{n,w}$	=	Total wind class *w* land area available for development in NERC Region *n*, sq. km,
$LDPLUS_{n,1,w}$	=	Land area needed to supply pre-existing wind generating capacity in NERC Region *n* in year *1*, by wind class *w*, sq k.

Equations 3B-4 and 3B-5 compute the amount of windy land area available for development at the beginning of a particular year by NERC Region and wind class:

If $LDPLUS_{n,1,2} < STAREA_{n,2}$, then

$$LDAREA_{n,1,2} = STAREA_{n,2} - LDPLUS_{n,1,2}$$
$$LDAREA_{n,1,3} = STAREA_{n,3} \qquad \textbf{(3B-4)}$$

If $LDPLUS_{n,y,2} \geq STAREA_{n,2}$, then

$$
\begin{aligned}
LDAREA_{n,1,2} &= 0.0 \\
LDPLUS_{n,1,3} &= \left[\frac{AREA_{1,2}}{AREA_{1,3}}\right] x \left[\frac{CF_{1,3}}{CF_{1,2}}\right] x \; (LDPLUS_{n,1,2} - STAREA_{n,2}) \\
LDAREA_{n,1,3} &= STAREA_{n,3} - LDPLUS_{n,1,3}
\end{aligned}
\qquad \textbf{(3B-5)}
$$

Subroutine CVNWLD (not used for first year)

Equation 3B-6 calculates the land are (in sq. km) needed to supply the wind generating capacity called for by the EMM by NERC Region, year and wind class:

$$
\frac{UCAPWNU_{n,y} + UCAPWNN_{n,y} - UCAPWNU_{n,y-1} - UCAPWNN_{n,y-1}) \; x \; Cl}{AREA_{y,1} \; x \; \frac{\pi}{4}} \qquad \textbf{(3B-6)}
$$

where:

$LDUSED_{n,y,w}$	=	Land area used to supply EMM-called for wind generating capacity in NERC Region *n* in year *y*, by wind class *w*, sq. km,
$UCAPWNU_{n,y}$	=	Total utility grid-connected wind electric capacity installed in NERC Region *n* through year *y*, GW,
$UCAPWNN_{n,y}$	=	Total nonutility grid-connected wind electric capacity installed in NERC Region *n* through year *y*, GW,
$CF_{y,w}$	=	Annual capacity factor for wind class *w* in year *y*,
$AREA_{y,w}$	=	Energy per unit swept rotor area for wind class *w* in year *y*, kwh/m^2,
π	=	3.141593,
α^{sp}	=	Scalar derived from 5D x 10D grid spacing of wind generator (α^{sp} = 50).

Equations 3B-7 calculates the land area needed to supply the wind generating capacity called for by the EMM when there is sufficient remaining land area to fulfill the request.

If $LDUSED_{n,y,w} < LDAREA_{n,y\text{-}1,w}$, then

$$\begin{aligned} LDAREA_{n,y,w} &= LDAREA_{n,y-1,w} - LDUSED_{n,y,w} \\ LDPLUS_{n,y,w+1} &= 0.0 \end{aligned} \qquad \textbf{(3B-7)}$$

Equation 3B-8 calculates the land area needed to supply the wind generating capacity called for by the EMM when the next lower quality wind resource has to be used because of insufficient remaining land of a higher quality. Since lower quality wind classes have lower capacity factors, the capacity factors serve as multipliers to adjust the amount of wind land area needed.

If $LDUSED_{n,y,w} \geq LDAREA_{n,y\text{-}1,w}$, then

$$\begin{aligned} REA_{n,y,w} &= 0.0 \\ US_{n,y,w+1} &= \left[\frac{AREA_{y,w}}{AREA_{y,w+1}}\right] x \left[\frac{CF_{y,w+1}}{CF_{y,w}}\right] x \ (LDUSED_{n,y,w} - LDAREA_{n} \\ EA_{n,y,w+1} &= LDAREA_{n,y-1,w+1} - LDPLUS_{n,y,w+1} \qquad for \ w = 1, \end{aligned} \qquad \textbf{(3B-8)}$$

where:

$LDAREA_{n,y,w}$	=	Wind class *w* land area available for development in NERC Region *n* after year *y*, sq. km,
$LDPLUS_{n,y,w}$	=	Land area needed to supply EMM-called for wind generating capacity in NERC Region *n* in year *y*, by wind class *w*, sq. km.

<u>Subroutine CALCAP</u>

Equation 3B-9 calculates the capacity factor for a particular wind class, NERC Region, year and subperiod:

$$\begin{aligned} WSFWIEL_{n,y,w,l} &= \left[\frac{SUBPER_{n,l}}{SLICE_{n,l}}\right] x \ CF_{y,w} \\ WSFWIEL_{n,y,1,l} &= WSFWIEL_{n,y,w_n,l} \end{aligned} \qquad \textbf{(3B-9)}$$

where:

$WSFWIEL_{n,y,w,l}$	=	Capacity factor for wind class *w* in NERC Region *n* in year *y* in subperiod *l*,
$SUBPER_{n,l}$	=	Energy fraction for subperiod *l* in NERC Region *n*,
$SLICE_{n,l}$	=	Hour fraction for subperiod *l* in NERC Region *n*,
$CF_{y,w}$	=	Annual capacity factor for wind class *w* in year *y*,

Subroutine CALMWA

Equation 3B-10 computes the total swept area by turbines for a particular wind class, NERC Region and year:

$$SWAREA_{n,y,w} = \frac{\frac{\pi}{4} \ x \ LDAREA_{n,y,w} \ x \ 10^6}{\alpha^{sp}} \qquad \textbf{(3B-10)}$$

where:

$SWAREA_{n,y,w}$	=	Swept rotor area available for wind class *w* in NERC Region *n* in year *y*, m^2,
$LDAREA_{n,y,w}$	=	Wind class *w* land area available for development in NERC Region *n* after year *y*, sq. km,
α^{sp}	=	Scalar derived from 5D x 10D grid spacing of wind generator (α^{sp} = 50).

Equation 3B-11 computes the available wind electric generation capacity in megawatts by wind class, NERC Region and year:

$$WSCWIEL_{n,y,w} = \frac{AREA_{y,w} \ x \ SWAREA_{n,y,w}}{CF_{y,w} \ x \ 10^3 \ x \ 8760} \qquad \textbf{(3B-11)}$$

where:

$WSCWIEL_{n,y,w}$	=	Available capacity for wind class *w* in NERC Region *n* in year *y*, MW,

$AREA_{y,w}$ = Energy per unit swept rotor area for wind class w in year y, kWh/m^2,

$CF_{y,w}$ = Annual capacity factor for wind class w in year y.

Equation 3B-12 computes the summation of the available wind generating capacity for all wind classes by NERC Region and year:

$$WCAWIEL_{n,y} = \sum_{w=1}^{3} WSCWIEL_{n,y,w} \qquad \textbf{(3B-12)}$$

where:

$WCAWIEL_{n,y}$ = Available capacity for all wind classes through class 3 in NERC Region n in year y, MW.

Appendix 3-C: Bibliography

Cohen, J.M., Schweizer, T.C., Hock, S.M., and Cadogan, J.B., "A Methodology for Computing Wind Turbine Cost of Electricity Using Utility Economic Assumptions," Proceedings of Windpower '89, American Wind Energy Association, September 1989.

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Energy Information Administration, "Component Design Report for Solar and Wind Submodules Renewable Fuels Module National Energy Modeling System," Draft, April 23, 1993.

Garver, L.L., "Effective Load Carrying Capability of Generating Units," IEEE Transactions on Power Apparatus and Systems, August 1966.

Hock, S.M., Thresher, R.W., and Cohen, J.M.; "Performance and Cost Projections for Advanced Wind Turbines," *Proceedings of ASME Winter Annual Meeting*, Dallas, TX, November 1990.

Princeton Economic Research, Incorporated, *Data Development Report for Wind Electric Submodule Renewable Fuels Module National Energy Modeling System*, February 24, 1993.

Princeton Economic Research, Incorporated, *Software Overview Report for Wind Electric Submodule Renewable Fuels Module National Energy Modeling System*, March 29, 1993.

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Science Applications International Corporation, "Renewable Energy Technology Evolution Rationales," Report in support of the National Energy Strategy for the U.S. Department of Energy, Office of Conservation and Renewable Energy, October 1990.

Schweizer, T. and Cohen, J., "A Technique for Estimating Project Risk: Beyond Traditional Sensitivity Analyses," Science Applications International Corporation, *Proceedings of the Windpower '88 Conference*, September 18-22, 1988.

Appendix 3-D: Model Abstract

Model Name:
Wind Energy Submodule

Model Acronym:
WES

Description:
Resource quality data and the yearly capacity factor are used to calculate wind farm performance data on a sub-yearly level, as required by the EMM. Calculations are made for each time slice, wind class, and region.

Purpose of the Model:
The purpose of the Wind Energy Submodule (WES) is to project the cost, performance, and availability of wind-generated electricity, and provide this information to the Electricity Capacity Planning (ECP) component of the Electric Market Module (EMM) for building the new capacity in competition with other sources of electricity generation.

Most Recent Model Update:
November 3, 1994

Part of Another Model?:
The Wind Energy Submodule is a component of the Renewable Fuels Module (RFM) of the National Energy Modeling System (NEMS).

Official Model Representative:
Perry M. Lindstrom
Coal, Uranium, and Renewable Fuels Analysis Branch
Energy Information Administration
(202) 586-0934

Documentation:
NEMS Documentation Report: *Renewable Fuels Submodule*, May 1995

Archive Media and Installation Manual(s):
Archived as part of the NEMS production runs.

Energy System Described:
A hybrid of various existing and proposed horizontal-axis wind turbines. Horizontal-axis wind turbines represent over 95 percent of U.S. generating capacity.

Coverage:

- Geographic: 15 NERC Regions: East Central, Texas, Mid-Atlantic, Mid-America, Mid-Continent, Northeast, New England, Florida, Southeastern, Southwest, Western, Rocky Mountain, California and South Nevada, Alaska, and Hawaii

- Time/Unit Frequency: Annual, 1990 through 2010

- Products: Electricity

- Economic Sectors: Electric utility sector, nonutility generators (NUGS)

- Model Structure: Sequential calculation of available wind capacity by NERC Region, wind class and year with a deduction of that year's installed capacity from the remaining available capacity

- Modeling Techniques: Accounting function of available windy land area and conversion of land area to swept rotor area and then to available generation capacity

- Special Features: Accounting for policy and/or production incentives.

Modeling Features:

DOE Input Sources:

Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91), June 1992.

Pacific Northwest Laboratory, Reports PNL-7789, DOE/CH 10093-4, and PNL-3195.

Non-DOE Input Sources:

Princeton Economic Research, Incorporated (PERI) — WNDSLICE preprocessing program.

Science Applications International Corporation (SAIC) — Cost and performance data as prepared for the National Energy Strategy project.

Electric Power Research Institute, *Technical Assessment Guide (TAG™)*, 1993.

Computing Environment:

- Hardware Used: IBM 3090
- Operating System: MVS
- Language/Software Used: VS FORTRAN, Ver. 2.05
- Memory Requirement: 35 Kb
- Storage Requirement: 23 Kb

- Estimated Run Time: .06 seconds
- Special Features: None.

Independent Expert Reviews Conducted:

None.

Status of Evaluation Efforts by Sponsor:

None.

Appendix 3-E: Data Quality and Estimation Processes

This Appendix discusses (1) the quality of the principal sources of input data used in the Wind Energy Submodule, along with a discussion of user-defined parameters and guidelines used to select them, and (2) estimation methods used to derive parameters.

Wind resources of the United States have been extensively charted and classified by the Pacific Northwest Laboratory (PNL). Three classes of wind resources, based on average annual wind speeds, are generally used. These classes correspond to PNL class 4 winds and higher, (speeds greater than 5.6 m/s (12.5 mph)) which represent the generally-accepted, lowest economic limit of wind speeds for grid-connected systems in the United States.

Data on wind resource quantity are maintained in the *Wind Resource Quantity File* as derived from published assessments or compilations of U.S. wind resources. It contains regional data on the land area (in square kilometers) estimated to be available for wind plant development, accounting for the exclusion of some land as a result of environmental and land-use considerations. WES uses the PNL "moderate" exclusion scenario. The percent of total windy land unavailable under this scenario consists of all environmentally protected lands (such as parks and wilderness areas), all urban lands, all wetlands, 50 percent of forest lands, 30 percent of agricultural lands, and 10 percent of range and barren lands. Within each region, the available land area is provided for each of the three levels of wind resource, according to the estimated average annual wind speed in that region and other factors. Lastly, since wind power increases significantly with height, a minimum height is usually specified for measurement and installation purposes, to achieve an associated wind power density.

The *Wind Resource Quality File* describes the variations in wind resource on a daily and seasonal basis, and estimates wind output during the different load condition subperiods to analyze the correlation with load profiles. The file is highly dependent on the raw wind speed file components chosen and incorporates data for many of the 975 stations in the Wind Energy Resource Information System (WERIS) from the National Climatic Data Center. The file also contains information on Load Duration Curve (LDC) subperiod definitions outside of the WES and the subperiod energy percentages. From this, WES estimates a capacity factor for a given subperiod. The specific subperiods correspond to season and time of day.

The *Cost and Performance of Installed Wind Turbines* have been monitored for almost a decade. During that period, a wind turbine database and turbine simulation program have been developed and refined. Also, analyses of manufacturer-supplied wind turbine power curves and installed costs were performed for a number of the best current, commercially available wind turbines. Wind turbine energy output estimates were made, assuming a Weibull wind speed distribution at several wind speeds, as well as corrections to wind speed for turbine hub height. Energy losses were based on field estimates from California wind plants. Average performance was estimated from the range of energy output data. Average costs were similarly calculated, and included major repairs such as rotor replacements and O&M costs.

The *Wind Turbine Cost and Performance Projections* to be used initially for the WES data files are based on the accelerated Federal wind technology R&D funding scenario used in the 1990 NES technology characterizations. The funding levels termed "accelerated" correspond most closely to present levels and emphases, namely R&D in the basic sciences and the "Advanced Wind Turbine" development program. There are also comprehensive cooperative programs with industry and utilities to assist in both near-term problem solving and long-term development.

The accelerated R&D scenario assumes that a significant portion of the "advanced turbine" technology is available by 1995, although scale-up to the complete 500 kW advanced turbine design is shown in year 2000. There is higher probability of success for the advanced turbine technology under the accelerated scenario because multiple designs will be able to be tested, resulting in lowered technical risk and multiple learning curves to prevent the problem of technological "lock-out" as discussed in the Technology Penetration CDR. In addition, technology transfer and design assistance programs could speed adoption and improve quality of the new technology. Further incremental improvements are experienced by the year 2005, and scale up to an optimum (1 MW) turbine, utilizing significantly better design tools developed by the basic science element of the program, should occur in the 2010 time frame. Small, incremental improvements should follow after 2010.

Estimates for the mid-term technology characterizations were based on (1) projections for the U.S Windpower 33M-VS turbine, and (2) analysis conducted by NREL of potential advanced design improvements based on technical insights from the current R&D program. The general approach used in the NREL analysis to determine the effects of design improvements on existing wind turbine technology can be described by three basic steps. First, a reference system was selected to represent current technology and its performance and costs were tabulated. Second, two configurations representing possible improvements to the reference design were identified, and the effect of each improvement on performance and cost was estimated. Lastly, estimated changes to wind plant cost of energy (COE) were calculated from the reference and improved design parameters.

5. Biofuels Supply Submodule

Model Purpose

The objective of the Biofuels Supply Submodule (BSS) is to provide the NEMS Petroleum Market Module (PMM) with supply curves for corn-derived ethanol, thus allowing the PMM to forecast transportation ethanol demand through the year 2010. A secondary objective is to report the energy content of ethanol produced for transportation fuel.

To be consistent with the market clearing mechanism adopted for NEMS, the BSS provides ethanol prices in the form of annual price-quantity curves. The curves, derived from an ethanol production cost function, represent the prices of ethanol at which associated quantities of transportation ethanol are expected to be available to refineries for blending with gasoline.

Relationship of the Biofuels Submodule to Other Models

The BSS's major NEMS linkages are with the Petroleum Market Module and the Coal Market Module (CMM). There is a two-way exchange of information between the BSS and PMM: the PMM provides the BSS with regional diesel fuel prices, while the BSS provides the PMM with delivered ethanol prices. The CMM serves as a source of energy price information for determining the total cost of converting corn into ethanol.

The delivered ethanol prices are provided to the PMM in the form of two supply curves, one for the East North Central Census Division (NEMS region 3), and one for the West North Central Census Division (NEMS region 4).[8] These two Census divisions constitute the major ethanol producing regions in the United States, and are the only two Census divisions considered for the AEO94 ethanol production forecasts.

To determine the delivered ethanol price, the contribution of the net cost of corn feedstock production must be factored in to the total unit price of ethanol. Diesel fuel prices, in dollars per gallon, are also considered as one of two energy cost variable inputs to the ethanol cost projected by the BSS. The other energy price input to the BSS's ethanol production cost function is the price of energy for corn feedstock processing and ethanol conversion. Coal prices are used as a proxy for industrial energy costs. Regional forecasts of energy prices (dollars per million Btu) to industrial consumers are supplied by the CMM.

[8]All regional data inputs to the BSS ethanol production cost function are by Petroleum Administration for Defense Districts (PADDs). The calculated ethanol prices and quantities are mapped to the two Census divisions prior to being written to the NEMS price/quantity COMMON blocks.

Inputs from other NEMS modules are summarized as follows:

- Regional delivered price of diesel fuel to the agricultural/transportation sector. This is obtained from the Petroleum Market Module, and is used for computation of corn feedstock prices.

- Regional delivered price of process energy to industrial consumers, obtained from the Coal Market Module, are used to compute the conversion costs in the regional ethanol supply curves.

- Yield on AA utility bonds. This is obtained from the Macroeconomic Activity Module, and is used for calculating the capital cost factor. (See Appendix 5-B, "Mathematical Description," for the derivation of the capital cost factor.)

A major source of data supplied to the BSS comes from runs of a model external to the NEMS environment. This model, the Agricultural Resources Interregional Modeling System (ARIMS), was the source of the corn feedstock cost-supply relationships used in the BSS's ethanol cost function. ARIMS was developed at the U.S. Department of Agriculture in the 1980's. The ARIMS is a linear programming resource allocation model that was restructured to account for the value of the by-products produced in the corn-to-ethanol conversion process and to project the net cost of corn feedstocks.[9] In other words, the projected by-product values were credited against the price of corn. The variability of the market price for the feedstock corn and the conversion by-products and the variable influences of competitive uses for corn (e.g., for producing corn syrup) gives rise to broad fluctuations in net corn feedstock prices. All of these factors are considered in the ARIMS model.

ARIMS was run for 1995, 2005, and 2015 to provide price-quantity data for ethanol feedstocks. The changes in the competitive agricultural infrastructure modeled by ARIMS typically occur so slowly that the three years of model projections were deemed sufficient to bracket the behavior within the forecast horizon.[10] Interpolation was used to derive data points for the remaining AEO94 forecast years. ARIMS is not integrated with NEMS, so that sensitivity analysis between NEMS and ARIMS is not currently feasible.

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[9]The net contribution of the cost of corn feedstocks to the price of ethanol is reduced over time by gradually improving conversion process yields. it is also affected by variations in the energy costs for producing corn. PDIESEL, the price of diesel fuel, was the proxy variable used to model the sensitivity of corn production costs to variable energy costs. Analyses were performed off-site and summary statistics are not currently available.

[10]Energy Information Administration, "Component Design Report for Biofuels (Ethanol) Supply Submodule - Renewable Fuels Model - National Energy Modeling System, Draft 7/2/92.

Modeling Rationale

Theoretical Approach

The BSS uses a process costing approach to model the impacts of net feedstock production costs plus the capital, operating, and process energy costs associated with converting the corn feedstocks to ethanol. In other words, each of the above factors contributes a part of the total price of ethanol projected by the BSS.

As mentioned above, the ARIMS supplied the data for the feedstock cost function variables. Since ethanol feedstock supply curves are a function of many factors (i.e., time, geographic location, demands for traditional agricultural commodities (domestic and foreign, crop and livestock), agricultural production technology, and land availability), the BSS needed the capability to relate such factors in a summary fashion to feedstock resource requirements under competitive agricultural market conditions. The ARIMS provides that capability with the use of a general equilibrium modeling framework.

The ARIMS was used to project corn crop demand and production resources and technology. Subject to constraints that were intended to capture the most important attributes of the agricultural market, the ARIMS model minimized the net cost of producing the specified quantities of corn produced as feedstock for ethanol, and the use of the feed by-products. The crop feedstock demand for ethanol production was set at various levels, with all other aspects of the model held constant. This allowed the linear program to develop sets of points that were used to estimate the step function feedstock supply curve.

Note that with this theoretical approach, only the agricultural, or feedstock production costs are modeled as a function of the total quantity of ethanol produced. The conversion plant process costs, (capital, operating, and process energy) are modeled as process cost which are independent of production quantities. The feedstock production cost components are estimated statistically, whereas the conversion process costs are determined from engineering concepts and data. Actual ethanol conversion process data are, for the most part, proprietary.

Fundamental Assumptions

Ethanol Production Capacity

An important modeling consideration is the imposition of a constraint on the amount of ethanol production capacity that can be added in any one year. Such a constraint would theoretically prevent unrealistically large increases in production capacity from occurring suddenly in response to potential structural market changes. On the other hand, our research determined that such capital expansion considerations are unnecessary for this modeling application because the lead time for capital expansion is very short and because the feedstock availability represents the major constraint to the expansion of ethanol production facilities.

For the AEO94, no structural changes to feedstock markets are assumed to occur during the forecast horizon. It is assumed that production capacity is utilized fully to meet refinery ethanol demand, and that there is sufficient ethanol production to meet refinery ethanol demand requirements.

Ethanol Production Costs

The ethanol supply-price curve reflects offsetting influences stemming from the effects of increased corn production and improvements in corn-to-ethanol conversion technologies. Net feedstock prices are projected to increase as production increases due to two primary reasons. First, land becomes scarcer, causing both land and feedstock costs to increase, and second, feed by-products become less valuable as larger feedstock quantities are produced. Over time, however, the technologies for growing corn and converting it to ethanol are projected to improve, resulting in downward pressure on ethanol production prices. The BSS models the net effect of all of these factors.

In addition to feedstock prices and quantities derived from ARIMS, the BSS requires feedstock conversion and energy cost data. The conversion cost data were derived from the U.S. Department of Agriculture Report 585 *Ethanol: Economic and Policy Tradeoffs*, and the analytical judgment of Dr. Anthony Turhollow. These costs were developed for the two Census Divisions (3 and 4) that comprise PADD region 2. Although the BSS has the ability to include ethanol production subsidies, they were set at zero for AEO94. The ethanol blender's excise tax credit, which is currently $0.054 per gallon of gasohol (10 percent ethanol, 90 percent gasoline), is modeled in the PMM.

Quantities of energy needed to convert corn to ethanol are assumed to be a positive linear function of input values for years 1, 16, and 26, and to remain constant, at the year 26 value, for years 27, 28, and 29. (The AEO94 runs utilized cost data only up to year 20). Current facilities use 50,000 Btu per gallon of ethanol produced; while state-of-the-art plants run as low as 40,000 Btu per gallon. These two values are used as input values for years 1 and 16, respectively, with later years based on a linear trend of the first two values. This linear interpolation procedure was based on the assumption that, over time, ethanol facilities have become more energy efficient, and will continue to do so as they convert corn to ethanol at higher conversion rates and adopt technology improvements such as organisms with higher tolerances for sugars and ethanol, and molecular sieves to separate water from products. The feedstock conversion energy prices used to develop the feedstock cost function are national prices. Regional prices were not necessary since the relationship between feedstock production costs and energy prices is thought to be relatively constant across regions.

Operating costs for feedstock conversion are also assumed to be a positive linear function of input values for years 1 and 16, but remain constant at the year 16 value for the remaining forecast years. The first-year 1990 value of $0.30 per gallon is an average plant cost for 1987, while the year 16 value of $0.27 per gallon is a projected state-of-the-art plant cost.

Treatment of Energy Crop Ethanol Feedstocks

Significant production of energy crops (e.g., grasses and short rotation trees) for ethanol production is not expected until about 2005. The conversion technology is at a stage wherein demonstration facilities for this technology are not expected to be operational until 1999, at the earliest. A few years of operating experience with the demonstration facilities will be required, and constructing the conversion facilities will also require several years time. Therefore, developing their supply functions for inclusion in the BSS will be deferred until a later AEO.

Alternative Approaches

Prior to the BSS, the EIA had no in-house modeling system for forecasting alcohol fuel production and demand. The ethanol forecasts for previous *AEO* reports were consensus forecasts prepared by Oak Ridge National Laboratory (ORNL), based on the inter-laboratory renewable fuels energy white paper prepared in 1990. Subsequent to the *AEO92*, a prototype modeling system, utilizing other existing models and a simple supply representation for the production of ethanol, was developed by ORNL. The prototype model consisted of a supply component, a demand component, and a market-clearing process.[11]

For the demand component, an existing model, the Alternative Motor Fuel Use Model (AMFU) was adopted. AMFU is a model used to forecast fuel usage, vehicle usage, and vehicle stock for up to a 40-year horizon. It has the characteristics of both an accounting model for vehicle stocks, and an econometric model with economic activity and prices of fuels for forecasting total fuel demand. The fuel use portion of AMFU assumes that vehicle usage is a function of fuel cost and economic growth, as estimated by statistical models. The proportion of vehicles using any particular fuel (i.e., gasoline, diesel fuel, ethanol) is represented by an algebraic system that includes the relative prices of alternative fuels.

The supply component of the prototype model was represented by a step-function supply curve. The energy crops alternative was represented as a flat supply curve. The sources of these supply functions were Abt Associates (1991) and Tyson (1990), respectively.

Finally, a market-clearing process was used to find an equilibrium solution. The demand model was run for the lowest available price (as determined by the supply curve) of ethanol. If the demand for ethanol exceeded the available supply at that price, the next step of the supply curve was tried. When demand met the available supply, the solution was complete.

Unlike the prototype, the BSS analyzes supply factors only. Market penetration of alternative-fueled vehicles will be determined in the Transportation Demand Module, and the quantities of ethanol blended with gasoline will be determined by the Petroleum Market Module. No

[11]Lee, R., S.M. Cohn, and R.D. Perlack. 1991. *Prototype of an Integrated Model for Projecting Biofuels Consumption.* Draft report prepared for Energy Information Administration, U.S. Department of Energy. Oak Ridge National Laboratory, Oak Ridge, TN.

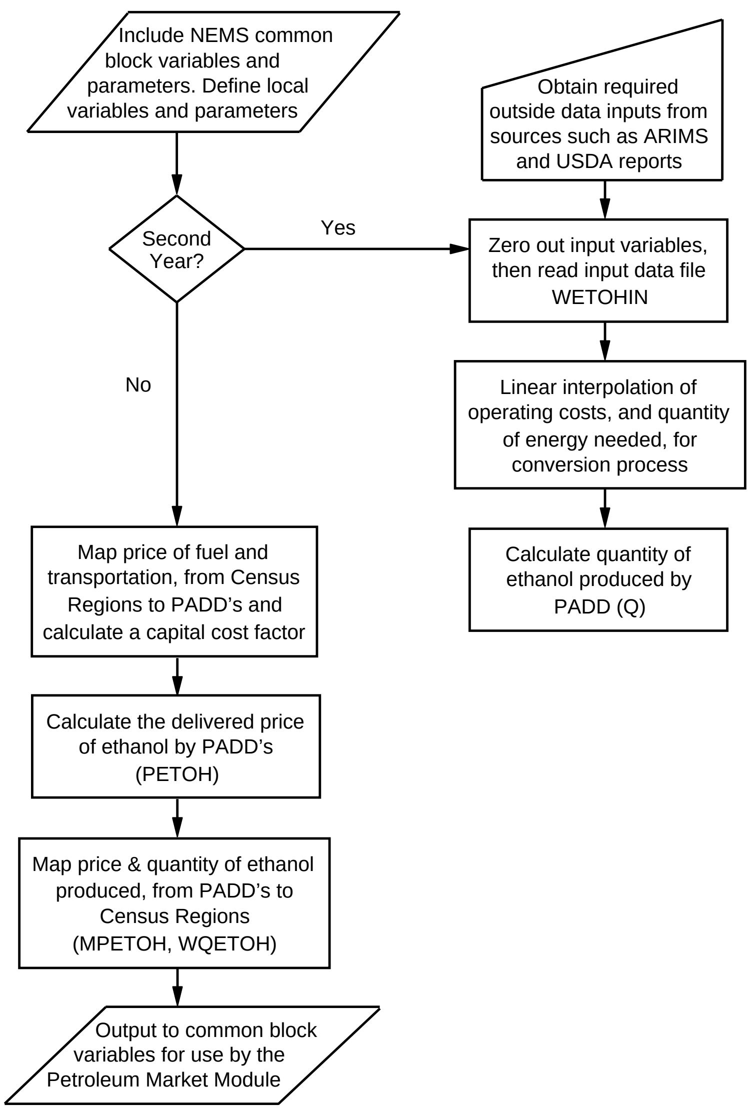
quantitative models for forecasting the production or consumption of ethanol have been identified for application in the BSS.

Biofuels Submodule Structure

Submodule Flow Diagram

A flow diagram showing the main computational steps and relationships of the Biofuels Supply Submodule is shown in Figure 4.

Figure 4. Biofuels Supply Submodule Flowchart



Key Computations and Equations

The main computations performed by the BSS involve the derivation of a single ethanol supply-price curve. The computations consist of three major steps:

1. Reading in ethanol supply and component cost data, and performing annual interpolations of data values provided on a multi-year basis,

2. Computation of ethanol supply curve (price/quantity) coordinates.

3. Derivation of delivered ethanol prices, calculated as a function of the supply curve coordinates from step 2.

Each of these steps is described below.

After reading in the single input data file, (WETOHIN), the BSS performs a simple linear interpolation on two of the input data variables. These two variables, indexed in Table 5A-1, are *OPCST* (operating cost for feedstock conversion technologies, exclusive of energy) and *QEN* (quantity of energy needed for feedstock conversion). The BSS gets data values for these variables for 3 years, corresponding to years 1, 16, and 26. Linear interpolations are performed to calculate intermediate yearly values.

The next step involves the calculation of feedstock costs as a function of quantity and year. Readers should recognize this as a standard interpolation routine (Equation 5-1) supplied to the data in Table 3. The input data file supplies historical data on costs, as well as ARIMS forecasts, at selected quantities of ethanol production.[12] Because significant ethanol production is currently limited to PADD 2 (Census divisions 3 and 4), the BSS calculates ethanol supply quantities and prices only for Petroleum Administration for Defense District (PADD) 2; supply quantities and prices for the other four PADDs are fixed at zero. The input file therefore supplies the skeleton, for selected years, of the corn production costs $COST_{p,t,e}$ at diesel price p, year t and production volume e. The input file also supplies the diesel price vector D_p and the vector Q_e that contains the quantities for each of the volume steps. Table 3 shows a the skeleton matrix used for AEO94. The BSS interpolates values for the $COST_{p,t,e}$ matrix for years t not given in the input file, and fills in the same cost at all diesel price points in the historical years.

After the skeleton matrix $COST_{p,t,e}$ has been filled in for all years, a supply curve for a given diesel price $PDIESEL_{pr,t}$ is interpolated from the matrix using the formula:

[12] All ethanol produced is assumed to be delivered to refineries.

Table 3. Corn Production Cost Skeleton Matrix ($/gal)

		Production Quantity Points (Billion gallons)					
Year	**Diesel Price ($/MMBtu)**	**0**	**2.5**	**5**	**7.5**	**10**	**20**
1995	6	0.214	0.315	0.346			
1995	8	0.233	0.336	0.372			
1995	10	0.250	0.359	0.402			
1995	12	0.272	0.378	0.425			
1995	14	0.279	0.408	0.454			
2005	6	0.266	0.301	0.331	0.371	0.420	
2005	8	0.279	0.327	0.347	0.383	0.435	
2005	10	0.306	0.379	0.379	0.407	0.466	
2005	12	0.333	0.394	0.412	0.431	0.488	
2005	14	0.351	0.415	0.436	0.470	0.514	
2015	6	0.255	0.281	0.300	0.326	0.351	0.442
2015	8	0.281	0.296	0.316	0.342	0.367	0.465
2015	10	0.307	0.327	0.349	0.374	0.400	0.511

$$_{t,e} = COST_{p-1,t,e} + \frac{PDIESEL_{pr,t} - D_{p-1}}{D_p - D_{p-1}} \left(COST_{p,t,e} - COST_{I}\right. \qquad \textbf{(5-1)}$$

where:

$FC_{pr,t,e}$ = Cost of producing corn in PADD pr=2 in year *t* for volume step *e* ($/gal),

$COST_{p,t,e}$ = Production cost matrix by diesel price step *p* in year *t* for volume step *e* ($/gal),

$PDIESEL_{pr,t}$ = Price of diesel oil in PADD *pr*=2 in year *t* ($/MMBtu), and

D_p = Diesel oil price step quantity for each step *p* ($/MMBtu),

with

$D_{p-1} < PDIESEL_{pr,t} < D_p$.

Indices

e	=	point on the supply curve, volume step 1 to 5
f	=	fuel(units in parentheses); 1=gasoline(gallons), 2=diesel(gallons), 3=LPG(gallons), 4=natural gas(MMBtu), 5=electricity(Kwh), 6=coal(MMBtu), 7=fuel for energy crop conversion (MMBtu).
i	=	crop; 1=corn, 2=energy crops
sr	=	Census Region, *sr*=1 to 9
pr	=	PADD, *pr*=1 to 5
t	=	year, $1990 \leq t \leq 2015$

The third major computational step involves the derivation of delivered ethanol prices for each PADD. The ethanol prices, *PETOH*, are calculated as a linear function of (1) the corn feedstock cost $FC_{pr,t,e}$ shown above, (2) the price of diesel fuel, which serves as a proxy for all of the energy costs of producing the feedstock and transporting it to the conversion facility, and (3) corn-to-ethanol conversion facility process cost contributions, namely, capital, non-energy-related operating costs, and process energy costs.

The delivered ethanol price equation is as follows:

$$PETOH_{i,pr,t,e} = FC_{pr,t,e} + CAPCST_{i,t} * CCF + OPCST_{i,t} + QEN_{i,t} * PEN_{pr,t} - SUB \qquad \textbf{(5-2)}$$

where:

$PETOH_{i,pr,t,e}$	=	Delivered price of ethanol produced from crop *i* in PADD *pr* in year *t* for volume step *e* for quantity of ethanol demand *Q* ($/gal),
$FC_{pr,t,e}$	=	Feedstock corn production cost for PADD *PR*=2 in year *t* for volume step *e* ($/gal),
$CAPCST_{i,t}$	=	Capital cost for conversion technology for crop *i* in year *t* ($/gal),
CCF	=	Capital cost factor (dimensionless),
$OPCST_{i,t}$	=	Operating costs, exclusive of energy, for crop *i* conversion technology in year *t* ($/gal),
$QEN_{i,t}$	=	Quantity of energy needed to convert crop *i* to ethanol in year *t* (MMBtu/gal),
$PEN_{pr,t}$	=	Price of energy used in the corn-to-ethanol conversion process in PADD *pr* in year *t* ($/MMBtu),
SUB	=	Subsidy for ethanol production ($/gal)

Appendix 5-A: Inventory of Variables, Data, and Parameters

This Appendix describes the variables, data inputs, and parameter estimates associated with the Biofuels Submodule. Table 5A-1 provides a tabular listing of model input data and input variable parameters. The table contains columns with information on item definitions, modeling dimensions, data sources, measurement units, and documentation page references. Similarly, Table 5A-2 provides an indexed listing of model output data and parameters.

The remainder of Appendix 5-A consists of detailed descriptions of data inputs and variables, including discussions on supporting data assumptions and transformations.

Table 5A-1. NEMS Biofuels (Ethanol) Supply Submodule Inputs

Model Variable	Definition and Dimensions	Source	Units	Page Reference
CAPCST	Capital cost for conversion technology for crop *i* in year *t*	USDA/ERS. 1988. Report #585	$/gallon	136, 142, 145, 146
COST	Cost of producing corn in PADD 2 at diesel price step *P* in year *t* at volume step *e*	ARIMS Output Trumble. 1994	$/gallon	135, 136, 142, 145
D	Values of diesel price steps *p*	Trumble. 1994	$/MMBtu	137
Q	Quantity at each volume step *e*	Trumble. 1994	billion gallons	137
MC_RMPUAANS	Yield on AA utility bonds for year *t*	Macroeconomic Market Module	Dimensionless	137
OPCST	Operating costs, exclusive of energy, for conversion technology of crop *i* in year *t*	USDA/ERS. 1988. Report 585	$/gallon	133, 138, 141
PADD2CR	Conversion rates to convert from PADD *pr* to Census Region *sr*	A. Turhollow	Dimensionless	138
PDSTR	Price of diesel for transportation in Census Region *sr* in year *t*	Petroleum Market Module	$/gallon	136, 138
PCLIN	Price of coal for industrial use in Census Region *sr* in year *t*	Coal Market Module	$/MMBtu	136, 138
QEN	Quantity of energy needed to convert crop *i* to ethanol in year *t*	Marland & Turhollow. 1991	MMBtu/gallon	137, 144, 146
QFUEL	Quantity of fuel type *f* used in the production of crop *i* in year *t*	Marland & Turhollow. 1991	Gallons for f=1,2,3 MMBtu for f=4 kWh for f=5	139

Table 5A-2. NEMS Biofuels (Ethanol) Supply Submodule Outputs

Model Variable	Definition and Dimensions	Source	Units	Page Reference
CCF	Capital cost factor	Accounting Parameter	Dimensionless	133, 141
HEATCONT	Heat content of ethanol	Value set to 3.5448	MMBtu/Bbl	139
PDIESEL	Price of diesel to industrial users in PADD *pr* in year *t*	Mapped from *PDSTR*	$/gallon	141
PEN	Price of energy used in the corn to ethanol conversion process in PADD *pr* in year *t*	Mapped from *PNGIN*	$/MMBtu	133, 141
PETOH	Delivered price of ethanol produced from crop *i* in PADD *pr* in year *t* for volume step *e* for quantity of ethanol demand *Q*	Endogenous Variable	$/gallon	133, 141
PETOHSRFACT	Conversion factor to convert prices from $/gallon to $/barrel	42 gallons equals one barrel	Gallons/barrel	143
Q	Delivered quantity of ethanol produced from crop *i* in PADD *pr* in year *t* for volume step *e* for price of ethanol *PETOH*	Endogenous Variable	Billion gallons/year	137
QSRFACT	Conversion factor to convert from million gallons per year to thousand barrels per day	set to value of 0.0652316, or $10^3/(42 * 365)$	Million bbl yrs/ billion gal days	142, 143
WPETOH	Delivered price of ethanol produced from crop *i* in Census Region *sr* in year *t* for volume step *e* for quantity of ethanol demand *WQETOH*	Mapped from *PETOH*. Read to PETTR variable in WRENEW common block	$/barrel	143
WQETOH	Delivered quantity of ethanol produced from crop *i* in Census Region *cr* in year *t* for volume step *e* for price of ethanol *WPETOH*	Read to QETTR variable in WRENEW common block	Million barrels/day	142

MODEL INPUT: *CAPCST*

DEFINITION: Capital cost for conversion technology for crop *i* in year *t*.

Given only for corn since the BSS is currently concerned only with corn as a feedstock. The current value is $2.00 per gallon, and is the same for all years. Located in the WETOHIN input data file.

SOURCE: USDA/ERS. 1988. *Ethanol: Economic and Policy Tradeoffs*. Agricultural Economic Report No. 585. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

MODEL INPUT: *COST*

DEFINITION: Outputs from the ARIMS model from cases executed at each of the price steps *p* and each of the quantity steps *e*.

Values represent the cost of producing the corn necessary to produce Q_e billion gallons of ethanol if the price were D_p in year *t*.

Values are given only for PADD 2. Quantities of ethanol produced outside of PADD 2 are currently insignificant, so all production from ethanol is shown in PADD 2. Located in the WETOHIN input data file.

SOURCE: ARIMS model outputs. David A. Trumble. 1994. *Estimation of supply Curve for Ethanol with Corn as the Feedstock.* Oak Ridge National Laboratory.

MODEL INPUT: *D*

DEFINITION: Diesel oil price steps *p*.

The diesel oil prices for which the ARIMS model was executed in each year. The BSS assumes that $COST_{p,t,e}$ was generated from a matrix of ARIMS cases for each D_p and Q_e.

SOURCE: ARIMS model inputs. David A. Trumble. 1994. *Estimation of supply Curve for Ethanol with Corn as the Feedstock.* Oak Ridge National Laboratory.

MODEL INPUT: *Q*

DEFINITION: Volume price steps *e*.

The ethanol volume steps for which the ARIMS model was executed in each year. The BSS assumes that $COST_{p,t,e}$ was generated from a matrix of ARIMS cases for each D_p and Q_e.

SOURCE: ARIMS model inputs. David A. Trumble. 1994. *Estimation of supply Curve for Ethanol with Corn as the Feedstock.* Oak Ridge National Laboratory.

MODEL INPUT: *MC_RMPUAANS*

DEFINITION: Yield on AA utility bonds for year *t*.

Located in the Macroeconomic common block, MACOUT.

SOURCE: Generated by the Macroeconomic Activity Module.

MODEL INPUT: *OPCST*

DEFINITION: Operating costs, exclusive of energy, for conversion technology of crop *i* in year *t*.

Given only for corn since the BSS is currently modeling only corn-derived ethanol. Values are: $0.30/gal. for 1990, $0.27/gal. for 2005. $0.27/gal. for 2015. Located in the WETOHIN input data file.

SOURCE: USDA/ERS. 1988. *Ethanol: Economic and Policy Tradeoffs*. Agricultural Economic Report No. 585. Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

MODEL INPUT: *PADD2CR*

DEFINITION: Conversion rates to convert from PADD *pr* to Census Region *sr*.

Values are given for each PADD and Census Region. Most PADD's map one-to-one to a Census Region. Only PADD 2 maps into two different Census Regions. Located in the WETOHIN input data file.

SOURCE: Generated by Dr. Anthony Turhollow, Oak Ridge National Laboratory, based on historical ethanol production from corn feedstocks.

MODEL INPUT: *PDSTR*

DEFINITION: Price of diesel for transportation in Census Region *sr* in year *t*.

Located in the NEMS Price common block (MPBLK).

SOURCE: Generated by the Petroleum Market Module.

MODEL INPUT: *PCLIN*

DEFINITION: Price of coal for industrial use in Census Region *sr* in year *t*.

Located in the Price common block, (MPBLK).

SOURCE: Generated by the Coal Market Module.

MODEL INPUT: *QEN*

DEFINITION: Quantity of energy needed to convert crop *i* to ethanol in year *t*.

Given only for corn since the BSS is currently concerned only with corn as a feedstock. Values, in million Btu per gallon, are as follows: 0.050 in 1990, 0.040 in 2005, 0.035 in 2015. This decreasing trend is based on the assumption that energy required decreases linearly over time. Located in the WETOHIN input data file.

SOURCE: Marland, G. and A.F. Turhollow. 1991. "CO_2 Emissions From the Production and Combustion of Fuel Ethanol from Corn." *Energy*, 16(11/12):1307-1316.

MODEL INPUT: *QFUEL*

DEFINITION: Quantity of fuel type *f* used in the production of crop *i* in year *t*.

Given only for corn since the BSS is currently concerned only with corn as a feedstock. Values cover seven different fuel types and 20 forecasts, and remain constant for the duration of the forecast horizon. The values for fuel type six, coal, are all zero. Fuel type seven is reserved for fuel provided for the feedstock conversion process. Located in the WETOHIN input data file.

SOURCE: Marland, G. and A.F. Turhollow. 1991. "CO_2 Emissions From the Production and Combustion of Fuel Ethanol from Corn." *Energy*, 16(11/12):1307-1316.

MODEL INPUT: *HEATCONT*

DEFINITION: Heat content of ethanol in transportation fuel, high-heating value.

SOURCE: Marland, G. and A.F. Turhollow. 1991. "CO_2 Emissions From the Production and Combustion of Fuel Ethanol from Corn." *Energy*, 16(11/12):1307-1316.

Appendix 5-B: Mathematical Description

This Appendix provides the detailed mathematical specification of the Biofuels (Ethanol) Supply Submodule as presented in the RFM FORTRAN code execution sequence. Subscript definitions are also as they appear in the FORTRAN code.

The ARIMS model is executed for a series of cases defined at a series of ethanol production quantities Q_e and diesel fuel prices D_p and years t, to create a matrix of corn production cost solutions $COST_{p,t,e}$ in $/gal. These are input to the BSS, and interpolated over years.

For a given NEMS diesel price $PDIESEL_{pr,t}$, where the PADD pr=2, the BSS interpolates a corn cost curve $FC_{pr,t,e}$ for PADD 2 that gives the cost in that year to produce each of the ethanol quantities Q_e at that diesel price. Here, $PDIESEL_{pr,t}$ represents the NEMS price of diesel fuel PDSTR, in $/MMBtu.

The delivered price of ethanol is calculated with the following equation:

$$\begin{aligned} PETOH_{1,pr,t,e} = {} & FC_{pr,t,e} + CAPCST_{1,t} * CCF \\ & + OPCST_{1,t} + QEN_{1,t} * PEN_{pr,t} \end{aligned} \qquad \textbf{(5B-1)}$$

where:

$PETOH_{i,pr,t,e}$	=	Delivered price of ethanol produced from crop i in PADD pr in year t for volume step e for quantity of ethanol demand Q ($/gal) Note: Since PETOH is given in $/gallons, the product of B1 * Q is also $/gallons. This is achieved by applying the unit ($10^{-9}$$ year/gal^2) to B1.
$PDIESEL_{\mathrm{pr,t}}$	=	price of diesel for PADD pr in year t ($/MMBtu)
$CAPCST_{i,t}$	=	capital cost for conversion technology for crop i in year t ($/gal)
CCF	=	Capital cost factor (dimensionless)
$OPCST_{i,t}$	=	operating costs, exclusive of energy, for crop i conversion technology in year t ($/gal)
$QEN_{i,t}$	=	quantity of energy needed to convert crop i to ethanol in year t (MMBtu/gal)
$PEN_{pr,t}$	=	price of energy used in the corn-to-ethanol conversion process in PADD pr in year t ($/MMBtu)

Indices

e	=	point on the supply curve, volume step 1 to 5
f	=	fuel(units in parentheses); 1=gasoline(gallons), 2=diesel(gallons), 3=LPG(gallons), 4=natural gas(MMBtu), 5=electricity(Kwh), 6=coal(MMBtu), 7=fuel for energy crop conversion (MMBtu).
i	=	crop; 1=corn, 2=energy crops
sr	=	Census Region, *sr*=1 to 9
pr	=	PADD, *pr*=1 to 5
t	=	year, $1990 \leq t \leq 2015$

The capital cost factor (CCF) used in equation 5B-2, which is based on a 30-year amortization period, is calculated as follows:

$$CFF = MC\_RMPUAANS_t * (1 + MC\_RMPUAANS_t)^{30} / ((1 + MC\_RMPUAANS_t)^{30} - 1) \quad \textbf{(5B-2)}$$

where:

MC_RMPUAANS	=	yield on AA-grade utility bonds (a Macroeconomic Activity Module output variable).

The quantity of ethanol used as a transportation fuel, $WQETOH_{cr,t,e}$, is derived from the following equation:

$$WQETOH_{(cr \subset 3,4),t,e} = Q_e \cdot PADD2CR_{2,3} \cdot QSRFACT \quad \textbf{(5B-3)}$$

where:

WQETOH	=	Quantity of ethanol used as a transportation fuel, in barrels per day, for Census division 3 and 4, year *t*, and supply step *e*,
Q_e	=	quantity of ethanol produced from crop *i* in PADD 2 in year *t* for volume step *e* (billion gallons/year),
$PADD2CR_{2,3}$	=	Conversion factors to convert from PADD 2 to Census Regions 3 and 4,
QSRFACT	=	Conversion factor to convert from million gallons per year to thousand barrels per day.

The price of ethanol used as a transportation fuel, $WPETOH_{cr,t,e}$, is derived from the following equation:

$$WPETOH_{(cr \subset 3,4),t,e} = PETOH_{1,pr,t,e} \cdot PADD2CR_{2,3} \cdot PETOHSRFACT \quad \textbf{(5B-4)}$$

where:

WPETOH	=	Price of ethanol used as a transportation fuel, in $ per barrel, for Census division 3 and 4, year *t*, and supply step *e*,
$PETOH_e$	=	Price of ethanol produced from corn in PADD 2 in year *t* for volume step *e* ($/gallon),
$PADD2CR_{2,3}$	=	Conversion factors to convert from PADD 2 to Census Regions 3 and 4,
PETOHSRFACT	=	Conversion factor to convert from gallons to barrels.

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Appendix 5-D: Model Abstract

Model Name:
Biomass (Ethanol) Supply Submodule

Model Acronym:
BSS

Description:
The BSS is a supply curve model for ethanol used for transportation fuel. It utilizes an ethanol cost function, NEMS energy price data, and outputs from an exogenous agricultural resource allocation linear programming model, to produce ethanol supply curves. The ethanol cost function models the impact of corn feedstock prices and supplies, energy prices, and feedstock conversion costs on delivered ethanol prices. The BSS's primary interaction is with the NEMS Petroleum Market Module (PMM).

Purpose of the Model:
The purpose of the Biofuels (Ethanol) Supply Submodule (BSS) is to provide annual corn-derived ethanol supply-cost curves for use by the Petroleum Market Module (PMM) in projecting ethanol requirements. For each year, the BSS calculates delivered ethanol prices for different ethanol demand levels. The ethanol supply/cost projection information by Petroleum Administration for Defense District (PADD) and by Census Region. These projections are made Through the year 2015. The BSS, as a part of NEMS, help the Energy Information Administration develop forecasts published in its *Annual Energy Outlook (AEO)*.

Most Recent Model Update:
October 29, 1993

Part of Another Model?:
The Biofuels submodule is a component of the Renewable Fuels Module (RFM) of the National Energy Modeling System (NEMS).

Official Model Representative:
Laurence Sanders
Coal, Uranium, and Renewable Fuels Analysis Branch
Energy Information Administration
(202) 586-2049

Documentation:
NEMS Documentation Report: *Renewable Fuels Submodule*, March 1994

Archive Media and Installation Manual(s):
Archived as part of the NEMS production runs.

Energy System Described:

Agricultural sector—corn feedstock production net of byproducts; corn feedstock requirements for ethanol production; ethanol as a refinery input for gasoline blending.

Coverage:

- Geographic: Nine Census Regions: New England, Mid Atlantic, South Atlantic, East North Central, West North Central, East South Central, West South Central, Mountain, and Pacific. Five PADD's: Atlantic Coast, North Central, South Central, Mountain, and Pacific

- Time Unit/Frequency: Annual, 1990 through 2015

- Products: Motor Fuel/Additives

Modeling Features:

NA

Non-DOE Input Sources:

Omnibus Reconciliation Act of 1990

- $0.54 per gallon subsidy for ethanol blenders

Marland & Turhollow, 1991

- Quantity of energy needed for process conversion
- Quantity of fuel used in the production of feedstocks

United States Department of Agriculture (USDA) - Report #585

- Capitol & operating costs for conversion technologies

United States Department of Agriculture (USDA) - (ARIMS)

- Percentage of ethanol produced by PADD's
- Feedstock cost data

Anthony Turhollow, Oak Ridge National Laboratory, Oak Ridge, Tennessee

- Beta coefficients derived from an analysis of ARIMS outputs

DOE Input Sources:

- EIA coal prices
- EIA diesel prices

Computing Environment:

- Hardware Used: IBM 3090
- Operating System: MVS
- Language/Software Used: VS FORTRAN, Ver. 2.05
- Memory Requirement: 26 Kb
- Storage Requirement: 14 Kb
- Estimated Run Time: 0.02 seconds
- Special Features: None.

Independent Expert Reviews Conducted:
None.

Status of Evaluation Efforts by Sponsor:
None.

Appendix 5-E: Data Quality and Estimation Processes

This Appendix provides an overview of the Agricultural Resources Interregional Modeling System (ARIMS), a main source of input data used in the BSS.

Agricultural Resources Interregional Modeling System (ARIMS)

The primary purpose of the national Agricultural Resource Interregional Modeling System (ARIMS) is as a system to analyze agricultural policies. Because resources and agricultural production practices differ by region, numerous regional attributes and responses to agricultural and resource policies can be evaluated in ARIMS. For example, policies can be evaluated that impact regional resource availability, farming techniques, resource prices, input availability, alternative levels of demand, and environmental allowances. The foremost use of the ARIMS, however, is to appraise future agricultural resource requirements.

ARIMS is a large linear programming model that includes numerous input coefficients and constraints. The inputs include projections of future resource availability, future demand levels and regional distribution of those demands, future commodity yields, and future changes in the ability of farmers to produce agricultural commodities. These projections are then used in a programming model and the composite effect of these individual impacts and the policy provisions introduced is analyzed.

The linear programming model of the agricultural sector is a set of mathematical relationships incorporating characteristics most relevant to agricultural production. The model minimizes the cost of producing and transporting agricultural commodities as required to meet pre-specified demands.

ARIMS divides the Nation into eight economic sectors. These eight sectors, integrated by a linear programming framework, are designed to represent the production processes and driving forces of U.S. agriculture.

The modeling system incorporates three different regional definitions. Production of agricultural commodities includes 105 Crop Producing Areas and 31 Livestock Producing Areas. The grazing production sector is specified for a third set of regions—34 ecosystems. The 31 Livestock Producing Areas also serve as the regional structure for non-water input purchases. In addition to the regions explicitly contained in the model structure, coefficients are developed by county, State, USDA farm production region and Major Land Resource Area.

Livestock markets (cattle, hogs, poultry) have an important role in determining the supply price of ethanol. The vast bulk of grain produced in the United States is fed to livestock, and the by-products of producing ethanol from corn (gluten meal, gluten feed, and distillers dried grains) are either fed to domestic livestock or exported. The by-products, including corn oil, from converting corn into ethanol are typically valued at about 50 percent of the raw corn cost.

The value of the by-products is directly proportional to the caloric and protein values of the feed by-products. Gluten meal (60 percent protein) and gluten feed (20 percent or more protein) are high in protein relative to corn (9 percent protein) and thus have a strong impact on soybean meal prices and vice versa. Soybean meal is 44 percent or more protein and is the main protein supplement for livestock. This competitive interaction is captured in the ARIMS model. As ethanol production from corn increases, the unit value of the feed by-products tends to decrease.

As an example, with corn at $2.50 per bushel the by-products are worth $1.25 per bushel, so the net feedstock cost is only $1.25 per bushel. At a conversion rate of 2.5 gallons of ethanol per bushel of corn, the net feedstock cost is only $0.50 per gallon instead of $1.00 per gallon.

The only use of ARIMS in this submodule is as a source of feedstock cost data. Regression equations relating the cost of corn to energy input prices were estimated from successive runs of the model. However, the summary statistics of those regressions are not currently available as they were conducted off-site and were not included in subsequent reports. For the next AEO, data will be obtained and analysis performed in order to estimate error terms and other relevant statistical information. ARIMS is run exogenously to NEMS, and is therefore not an integrated component of the BSS.

6. Wood Submodule

Model Purpose

Model Objectives

The purpose of the Wood Submodule is to furnish cost and performance characteristics of a wood burning electricity generating technology to the Electric Market Module (EMM) of the National Energy Modeling System (NEMS). The submodule utilizes a regional wood supply schedule from which the wood price is determined. The wood supply schedule is based on the accessibility of wood resources by the consuming sectors from existing timber resources excluding future wood energy crops.

The basic data inputs to the submodule include:

- wood resource inventory and cost data from the U.S. Forest Service,
- wood distribution and preparation cost data,
- annual wood energy consumption by sector,
- conversion factors for transforming (1) wood tonnage information into Btu energy equivalents, (2) U.S. Forest Service wood inventory region data into Census Division data, and (3) Census Division wood prices into NEMS Electricity Region prices,

The Submodule's outputs consist of (1) wood energy conversion performance values, (2) operating and maintenance costs (fixed and variable) by Census Division, NERC Region and year, and (3) capital costs for a wood-fired power plant. Prices of short rotation biomass (woody and herbaceous) energy crops are not currently reflected in the wood supply schedule.

Relationship of the Wood Submodule to Other Models

The Wood Submodule interacts with other NEMS modules by both accepting inputs and passing outputs via the Renewable Fuels Model (RFM) shell. It does not interact with other submodules in the RFM. Regional wood consumption data from the commercial, industrial, and electricity modules are used in the wood module to determine the regional wood supply price. A total capacity potential is calculated from regional supply curve data and each year, the accumulated capacity from the EMM is measured against this limit and constraint if it exceeds the limit.

The Wood Submodule outputs include wood prices consistent with the quantities demanded. These are supplied to the EMM to determine capacity, dispatched power, and electricity prices.

Modeling Rationale

Theoretical Approach

The wood submodule provides regional wood supply curves for noncaptive markets. The supply curves are based on a detailed analysis of historical wood consumption for a set of wood sources in the industrial, electric generating, commercial, and residential sectors.

Prior to the development of NEMS, electricity from wood was estimated by EIA as a series of econometric equations based on historical wood use from various sources and the relationship between wood consumption and key variables. For utilities, projections of wood facility capacity and capacity utilization factors were made off-line and included in the EMM. No competition between wood and other sources of electricity generation was modeled; rather, the use of wood decreased the requirements from other sources of generation.

The wood use in NEMS is decomposed and modeled as two distinct markets, the *captive* and *noncaptive* wood markets. The captive market pertains to users with dedicated wood supplies that combust wood byproducts resulting from the manufacturing process (i.e., the pulp and paper and forest products industries). The wood waste combustion in captive markets serves the dual role of energy supplier and waste disposal method. The captive wood market is modeled by the industrial module of NEMS.

The noncaptive wood market is represented in the Wood Submodule of the RFM. The noncaptive market is defined to include the commercial and electric utility sectors, as well as the noncaptive portion of the industrial sector. It is necessary to include commercial and industrial consumption in order to properly estimate supply and demand conditions, as these represent alternative economic uses of the wood supply. There is an additional noncaptive market serving residential uses of wood. This market is modeled in the residential demand module.

Because of the scarcity of reliable data and the relatively small size of the noncaptive market, EIA decided to develop a fairly simple model structure consisting of one supply schedule per region. This schedule defines the quantity and cost relationships of wood resources accessible by all noncaptive, non-residential consumers; it is based on an off-line data accounting procedure that aggregates supply/price information from several U.S. Forest Service (U.S.F.S.) wood resource inventory and price surveys.

Wood Classification

The total wood supply consists of distinct resources which are represented in aggregated regional supply schedules. The U.S.F.S. has divided wood resources into 15 categories (Table 4). Ten of the categories supply the commercial, industrial and utility sectors. Black liquor is used within the pulp and paper industry, a "captive" industry.

Table 4. U.S. Forest Service Wood Resource Categories by Type and Demanding Sectors

	Sector		
	Industrial[a]	Commercial	Utility
Forest			
Live			
Dead			
Nonforest			
Logging residues	x	x	x
Whole Tree Chips			
Softwoods	x	x	x
Hardwoods	x	x	x
Mill Residues			
Softwood Coarse	x	x	x
Hardwood Coarse	x	x	x
Softwood Fine	x	x	x
Hardwood Fine	x	x	x
Softwood Bark	x	x	x
Hardwood Bark	x	x	x
Other Wood	x	x	x
Black Liquor [b]			
Energy Crops	x	x	x

[a]Noncaptive industrial.
[b]Black liquor is only used by the pulp and paper industry.

Fundamental Assumptions

A basic assumption of the Wood Submodule is that the supply price for noncaptive wood energy is the same across all sectors. This assumption allows the construction of a single supply schedule for all sectors to yield a supply price for the electric utility sector.

Another important fundamental assumption relates to the treatment of wood transportation costs. The difficult aspect of building supply curves for wood is modeling the economic accessibility to the resource, rather than estimating the physical amount of wood that can be used. This submodule assumes a fixed "typical" transportation distance in calculating costs. Because no interregional wood trade exists, it is assumed that no wood is transported among NEMS regions.

The wood supply analysis was conducted in 1984 and is based on 1976 forest inventory data. Logging residue and whole tree data are obtained from an unpublished manuscript by McQuillan, et al., in which the authors projected waste wood inventory and retrieval costs from 1990 through 2030. Forest management has changed dramatically since the study was undertaken in 1984. Recently, the practice of clear-cutting in old-growth forests has come under scrutiny for its impacts on endangered species such as the Northern spotted owl. It appears increasingly likely that large portions of the remaining old-growth forest will be set aside as wildlife preserves, and governments will probably place new restrictions on activities in second-growth federal and state forests. These new environmental restrictions will reduce the softwood supply and lead to more intensive use of existing waste wood inventories for furniture making, construction and other uses, resulting in higher prices and smaller inventories than projected by the authors. Working to mitigate this trend are restrictions on raw log exports from federal and state lands, increasing the proportion of logs from federal and state lands that are milled domestically.

Alternative Approaches

As mentioned above, the Wood Submodule is based on the simplifying assumption that a single regional supply schedule for all wood resources is appropriate for the electric generating sector. However, this simplification may not be able to capture all of the important dynamics in wood markets. Wood costs increase rapidly as the distance transported increases. Wood is used relatively near its source, unlike coal, gas, or oil. A concentrated use in a small area is difficult to represent in the large regions of NEMS, where the average wood share of energy used could be quite small. Large-scale facilities could lead to transportation problems (e.g., too many trucks required for delivering wood). While this submodule estimates supply curves for the production of wood, the transportation distance of a facility from the wood supply can make up a significant share of the delivered cost. In this module, a typical transportation distance for each Census Division is assumed. A more complete representation would include transportation supply curves.

Wood Submodule Structure

Data Analysis

The Wood Submodule's computational procedures consist of two basic routines: derivation of the all-sector supply schedule and aggregation of all quantities and prices into single sectoral values. This section outlines the procedures and equations associated with these two routines.

All-Sector Supply Schedule

The regional wood energy quantities for the all-sector supply schedule, $Q_{total,R}$, are calculated as the sum of wood energy quantities for each wood resource available in each Census division R:

$$
\begin{aligned}
{}_{,R} = \; & (Q_{hardwood\ chips,R} + Q_{softwood\ chips,R}) \\
& + (Q_{hardwood\ logging\ residue,R} + Q_{softwood\ logging\ residue,R}) \\
& + (Q_{course\ mill\ residue,R} + Q_{fine\ mill\ residue,R} + Q_{bark\ mill\ resi} \\
& + Q_{other\ wood,R}
\end{aligned}
\tag{6-1}
$$

The wood quantities and associated prices are aggregated using a Lotus 1-2-3 spreadsheet. The following sections outline the processing steps associated with the aggregation of quantity and price data for each regional supply schedule wood resource. These processing steps are performed manually off-line.

Supply Schedule Processing Steps: Whole Tree Chips and Logging Residues

1. Data for whole tree chips and logging residues are obtained from U.S. Forest Service projections. There are separate inventories for hardwoods and softwoods.

2. Price data are converted from 1980 dollars per thousand cubic feet to 1987 dollars per million Btu based on the implicit GNP price deflator of 85.7 in 1980 and 117.4 in 1987. The density of softwood is assumed to be 35 pounds per cubic feet. For hardwood a density of 40 pounds per cubic feet is assumed. Quantity data are converted from million cubic feet to trillion Btu using the density for hardwood and softwood, and assuming 15-percent moisture and a heat content of 17 million Btu per dry ton of wood.[13]

3. Whole tree chip supply data are represented as an inventory. Annual supplies must be obtained by allocating the inventory according to the rate of annual sustainable harvesting of the resource. A constant annual rate of 5 percent of the total inventory supply is assumed. Logging residue data is already presented as annual supply quantities, so no adjustments are necessary.[14]

4. The supply schedules for hardwood and softwood are combined with the use of a price lookup algorithm. A price (and associated quantity) from either the hardwood or softwood schedule is first selected. The price from the other wood schedule that is closest to but not greater than the selected price is used as the other lookup price. The quantities associated with the two lookup prices are then added together. This lookup

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[13]Turhollow, et al., Oak Ridge National Laboratory, "Data and Sources, Biomass Supply, Draft, 1993.
[14]Ibid.

algorithm results in wood energy supply quantities for all price points represented by both hardwood and softwood supply schedules.

5. Data is then mapped to Census divisions using factors based on the 1987 wood inventory data obtained from the U.S. Forest Service.

Supply Schedule Processing Steps: Mill Residues

1. Mill residue data for 1987 is obtained from U.S. Forest Service for three types: coarse wood, fine wood, and bark. Each type of mill residue is divided into four uses: fiber, fuel, other, and unused. The fiber and "other" categories are not used for energy production.

2. The amount of fine wood and bark residues that are used for fuel in captive markets are excluded. Fine wood and bark residues available to the nonresidential, noncaptive market are estimated to be 10 percent of the total fine wood/bark residue supply. This percentage was obtained by assuming that the nonresidential, noncaptive share of the total wood supply (8.7 percent) is a good proxy for the nonresidential, noncaptive share of the fine wood/bark residue supply.[15]

3. The Forest Service estimates that 42.9 trillion Btu of mill residues are not used at all. It is arbitrarily assumed that 50 percent of this quantity is available for fuel.[16]

4. The total quantity of each type of residue is determined from the percentages of wood available and the quantity data provided by U.S.F.S..

5. Quantities are converted from thousand tons at 12 percent moisture to trillion Btu based on the conversion of 17 million Btu per dry ton.[17]

6. U.S. Forest Service mill residue data are disaggregated into three supply regions: North, South, and West. Wood inventory data for 1987 is used to map the three supply regions into Census Divisions. It is conceptually better to use mill residue consumption by state for Census Division mapping purposes, but such data are unavailable.

7. The quantities from each type of residue are added together to provide an overall quantity for each Census division.

8. Price data for mill residues were obtained from the U.S. Forest Service. Prices for each type of residue are obtained for both hardwood and softwood.

[15]Ibid.
[16]Ibid.
[17]Ibid.

9. The prices of hardwood and softwood are combined to form a weighted average price for each type of residue.

10. Prices are converted form 1986 dollars per cubic meter to million Btu based on the following assumptions: the GNP price deflator for 1986 is 113.8 and 117.4 for 1987; there are 35.29 cubic feet in a cubic meter; and one cubic foot is 37.5 pounds at 12 percent moisture.

11. A transportation cost was added to get a delivered price based on an assumed trip of 20 miles, a cost of $0.14 per dry ton mile. The prices are then mapped to Census divisions.

Supply Schedule Processing Steps: Other Wood

1. Data on other wood use (including furniture, construction debris, waste pallets, and demolition wastes) are obtained from the U.S. Forest Service.

2. Price data are converted from 1986 dollars per cubic feet to 1987 per million Btu based on the following assumptions: the GNP price deflator is 113.8 in 1986 and 117.4 in 1987; there are 35.29 cubic feet in a cubic meter; there are 37.5 pounds per cubic foot at 12 percent moisture; and there are 17 million Btu per dry ton.

3. The quantity of other wood is converted from million cubic feet to trillion Btu. The price data and quantity are then mapped to Census divisions using 1990 population estimates.

Key Computations and Equations

The wood submodule consists of one FORTRAN subroutine. It computes the regional wood supply price given the current regional wood consumption passed from the industrial, commercial, and electric generating modules. The wood price is added to the variable operating cost and passed to the Electricity Planning Submodule (ECP) along with other cost-performance figures (i.e. capital cost, fixed operation and maintenance cost, capacity factors, and heat rates).

The wood quantity-price relations are implemented in a matrix representing the supply curve as step functions. A linear interpolation scheme is used to determine the wood price given a wood quantity.

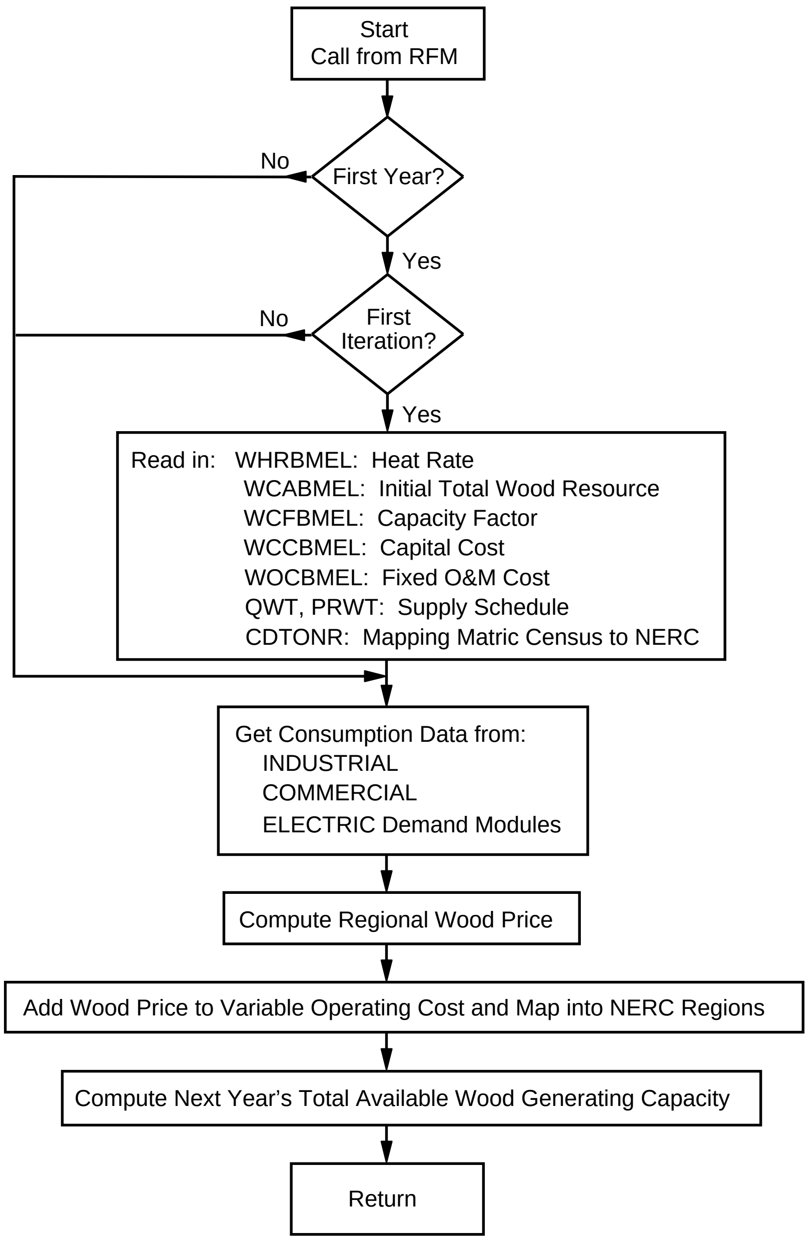
Since the quantity-price relations are established for Census regions, and the cost and performance characteristics of the biomass technology are defined for NERC regions, a geographic mapping was necessary to generate wood prices by NERC regions (Table 6A-2).

In addition to the assignment of cost performance characteristics, the wood submodule passes the maximum available electricity generating capacity using wood to the ECP. This capacity limit is computed by decremanting the initial total potential by already installed capacity and for each subsequent year, decrementing the last year's unplanned new capacity form the previous limit. The initial total generating capacity for each region is determined by dividing the maximal quantity of wood reserves in the supply curve by the heat rate, the capacity factor, and 8760 as the number of hours per year.

The technology represented by the cost and performance values for new capacity is the Integrated Gasification Combined Cycle (IGCC) system for wood. The unit cost is modular and capable of being shop fabricated. The cost values include storage and wood handling, magnetic separators, and ash handling equipment. The gasifier is equipped with solid and gas recycling systems. A modular hot gas filtration unit is included in the cost assumptions.

The procedural execution of the wood subroutine is illustrated in Figure 5.

Figure 5. Wood Submodule Flowchart



Appendix 6-A: Inventory of Variables, Data, and Parameters

Appendix 6-A provides information on variables used in the Wood Submodule. Table 6A-1 gives a complete listing of all variables including definitions and dimensions, sources, measurement units, and page references. Variables are classified as Submodule data inputs, calculated variables, and Submodule outputs. Following Table 6A-1 are detailed descriptions of each input data item.

Table 6A-1. NEMS Wood Submodule Inputs and Variables

Model Variable	Definition and Dimensions	Source	Units	Page Reference
INPUTS				
CDTONR	Conversion factors for converting Census division *R* to NERC Region *RN*		Unitless	163
PRWT	Price of wood for supply function step *I*	USDA, Forest Service	$/MMBtu	163
QWT	Quantity of wood for supply function step *I* in Census division *R*	USDA, Forest Service	Trillion Btu	163
WCCBMEL	Capital cost for wood technology in NERC Region *RN* in year *T*	NREL	$/kW	173
WCFBMEL	Capacity factor for wood technology electricity sector in NERC Region *RN* in year *T*	NREL	Unitless	173
WVCBMEL	Variable O&M costs for wood technology electricity sector in NERC Region *RN* in year *T*	model determined	mills/KWh	173
WOCBMEL	Fixed O&M cost for wood technology electricity sector in NERC Region *RN* in year *T*	NREL	$/kW	173

Table 6A-1. NEMS Wood Submodule Inputs and Variables (Continued)

Model Variable	Definition and Dimensions	Source	Units	Page Reference
VARIABLES				
PELCM	PRICE OF ELECTRICITY IN THE COMMERCIAL SECTOR IN CENSUS DIVISION *R and year T-1*	NEMS Commercial Module	$/kWh	177
PELIN	Price of electricity in the industrial sector in Census division *R* and year *T-1*	NEMS Industrial Module	$/kWh	177
QBMCM	Quantity of wood consumed in the commercial sector in Census division *R* in year *T*		MMBtu	177
QBMEL	Quantity of wood consumed by utilities in Census division *R* in year *T*		MMBtu	177
QBMIN	Quantity of wood consumed in the industrial sector in Census division *R* in year *T*		MMBtu	177
QUCI	Quantity of wood consumed by all sectors		MMBtu	177
OUTPUTS				
CABMEL	Capacity for utilities in NERC Region *RN* in year *T1*		MW	
WCCBMEL	Capital cost for wood technology in NERC Region *RN* in year *T*	NREL	$/kW	173
WCFBMEL	Capacity factor for wood technology electricity sector in NERC Region *RN* in year *T*	NREL	Unitless	173
WVCBMEL	Variable O&M costs for wood technology electricity sector in NERC Region *RN* in year *T*	NREL	mills/KWh	173
WOCBMEL	Fixed O&M cost for wood technology electricity sector in NERC Region *RN* in year *T*	NREL	$/kW	173
PBMCM	Price of wood for the commercial sector in Census division *R* in year *1*		$/MMBtu	177
PBMEL	Price of wood for utilities in Census division *T* in year *T1*		$/MMBtu	177
PBMIN	Price of wood for the industrial sector in Census division *R* in year *T1*		$/MMBtu	177
PUCI	Price of wood for all sectors		$/MMBtu	177

Because the available wood resource data are structured by cencus regions and NEMS is structured by a variation of NERC regions, it is necessary to provide for that transition. This is done in a matrix in which estimates of wood quantities for each census region are allocated to the NERC regions

The resulting conversion factors are listed in the following table:

Table 6A-2. Map of Census Divisions to NERC Regions

	Census Division									
NERC Region	1	2	3	4	5	6	7	8	9	10
1	0	0.06	0.90	0	0.12	0.23	0	0	0	0
2	0	0	0	0	0	0	0.03	0	0	0
3	0	0.36	0	0	0	0	0	0	0	0
4	0	0	0	0.05	0	0	0	0	0	0
5	0	0	0.10	0.05	0	0	0	0	0	0
6	0	0.58	0	0	0	0	0	0	0	0
7	1.00	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0.08	0	0	0	0	0
9	0	0	0	0	0.80	0.65	0	0	0	0
10	0	0	0	0.90	0	0.12	0.97	0	0	0
11	0	0	0	0	0	0	0	0.70	0.90	0
12	0	0	0	0	0	0	0	0.30	0	0
13	0	0	0	0	0	0	0	0	0.10	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0

<u>MODEL INPUT</u>: *CDTONR*

<u>DEFINITION</u>: Conversion factors for converting Census division *R* to NERC Region *RN*

<u>SOURCE</u>: Oak Ridge National Laboratory, "Data and Sources Biomass Supply", Draft prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993.

MODEL INPUT: *PRWT* and *QWT*

DEFINITION: Price and quantity from the all-sector supply schedule for supply function step *I*

PRWT and *QWT* represent the price quantity relation for a wood composite consisting of the following wood types: 1) whole tree chips, 2) logging residues, 3) mill residues, and 4) other wood. Data on each wood type are collected and compiled individually and then combined to one all-sector wood supply schedule. The supply schedule is shown in Table 6E-1.

Whole Tree Chips

The wood resource designated for whole tree chips are estimated from timber inventory data collected and compiled by McQuillan, et al. (1984). The availablity of wood for whole tree chipping is based on a sustainable timber cutting cycle of 20 years. This means that on a sustainable basis, 1/20 of the inventory is available in any one year.

The inventory distinguishes between softwoods and hardwoods in nine U.S.F.S. regions. McQuillan et al. reported the prices as a delivered supply price to large users which does not include the additional cost for wood drying.

The quantities are mapped from the U.S.F.S. regions to census divisions using a mapping matrix for whole tree chips.

Tables 6A-3a, 6A-3b, and 6A-3c show the wood supply schedule for whole tree chips. Under each price level, the quantity of material in each region at that price is indicated.

Table 6A-3a. Supply Schedule for Whole Tree Chips by Census Region
(in 1987 Dollars/Million Btu and Trillion Btu)

	1987$/Million Btu										
	0.542	0.711	0.813	0.948	1.083	1.185	1.354	1.422	1.625	1.659	1.896
Region	**Trillion Btu**										
New England	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	5.9	15.9	58.1
Middle Atlantic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	6.1	16.4	60.0
East North Central	0.0	0.0	0.0	0.2	0.2	0.2	0.2	7.2	8.5	30.6	86.1
West North Central	0.0	0.0	0.0	0.1	0.1	0.1	0.1	4.0	4.8	16.8	47.4
South Atlantic	0.0	0.0	0.0	0.0	0.0	67.4	75.4	219.7	233.1	300.7	334.9
East South Central	0.0	0.0	0.0	0.0	0.0	9.1	9.7	45.4	48.6	118.4	186.3
West South Central	0.0	0.0	0.0	0.0	0.0	8.1	8.6	39.2	41.7	99.7	149.1
Mountain	0.0	0.0	0.0	0.0	0.0	0.2	1.6	5.0	13.9	21.0	58.2
Pacific	0.0	0.0	0.0	0.0	0.0	0.0	6.9	8.6	38.0	45.6	90.7
Total	0.0	0.1	0.1	0.3	0.4	85.1	102.5	335.1	400.7	665.0	1071.1

Table 6A-3b. Supply Schedule for Whole Tree Chips by Census Region
(in 1987 Dollars/Million Btu and Trillion Btu)

	1987$/Million Btu										
	2.133	2.167	2.370	2.438	2.709	2.844	3.250	3.318	3.792	4.266	4.334
Region	**Trillion Btu**										
New England	84.6	87.9	93.7	99.8	101.8	109.4	109.9	115.4	140.6	217.6	252.0
Middle Atlantic	87.3	90.7	96.7	103.1	105.1	113.0	113.5	119.1	145.1	224.7	260.2
East North Central	123.5	125.4	126.5	127.4	127.8	133.4	133.5	136.8	161.6	338.6	378.6
West North Central	68.2	69.5	70.2	71.1	71.4	74.5	74.6	76.4	90.3	187.3	209.7
South Atlantic	348.3	350.3	356.9	360.0	361.4	561.8	684.3	1169.7	1284.4	1323.2	1339.8
East South Central	206.4	208.0	213.1	214.0	215.2	267.9	294.6	542.7	698.5	739.0	753.1
West South Central	159.5	160.5	164.9	165.5	166.5	212.5	236.4	457.6	592.0	592.2	596.7
Mountain	61.4	79.9	81.1	101.6	106.8	111.8	118.6	122.5	183.3	213.2	259.8
Pacific	100.0	118.6	125.8	134.8	146.0	153.7	218.6	234.4	379.3	388.8	414.5
Total	1239.2	1290.8	1328.9	1377.3	1402.0	1738.0	1984.0	2974.6	3675.2	4224.5	4464.6

Table 6A-3c. Supply Schedule for Whole Tree Chips by Census Region
(in 1987 Dollars/Million Btu and Trillion Btu)

	1987$/Million Btu				
	4.740	4.876	5.214	5.417	5.688
Region	**Trillion Btu**				
New England	278.4	303.0	305.2	305.8	305.9
Middle Atlantic	287.4	312.8	315.1	315.7	315.8
East North Central	443.2	465.7	465.8	465.8	465.8
West North Central	245.1	258.8	258.9	259.1	259.1
South Atlantic	1352.6	1364.4	1365.5	1365.8	1365.8
East South Central	767.8	773.0	773.0	773.0	773.0
West South Central	596.7	596.8	596.8	596.8	596.8
Mountain	261.4	321.4	322.6	333.6	333.7
Pacific	423.3	456.8	460.1	462.1	462.1
Total	4655.9	4852.8	4862.9	4877.6	4878.0

Logging Residues

The data on available logging residues are also obtained from the report by McQuillan et al. (1984). Logging residues in this report are listed for softwoods and hardwoods separately in each of the nine U.S.F.S. regions. The price data represent the price for the wood including delivery to large users. They do not include the additional cost for drying.

The supply schedule for softwoods and hardwoods are combined for each U.S.F.S. region and shown in Tables 6A-4a and 6A-4b. The structure of this table is similar to that for whole tree chips, however, the prices start at a slightly higher level.

Table 6A-4a. Total Logging Residue Supply Schedule by Census Regions
(in 1987 Dollars/Million Btu and Trillion Btu)

	1987$/Million Btu											
	1.185	1.354	1.422	1.625	1.659	1.896	2.133	2.167	2.370	2.438	2.709	2.844
Region	**Trillion Btu**											
New England	0.0	0.0	0.0	0.0	0.0	4.8	12.8	15.4	15.4	15.4	16.2	19.0
Middle Atlantic	0.0	0.0	0.0	0.0	0.0	4.9	13.2	15.9	15.9	15.9	16.8	19.6
East North Central	0.0	0.0	0.0	0.0	0.7	2.9	11.4	11.7	11.7	11.7	11.8	14.6
West North Central	0.0	0.0	0.0	0.0	0.4	1.6	6.2	6.4	6.4	6.6	6.7	8.2
South Atlantic	0.0	2.3	20.8	27.1	51.9	77.8	81.6	82.9	82.9	82.9	83.3	84.6
East South Central	0.0	0.0	2.0	5.2	11.3	25.4	30.6	32.0	32.0	32.0	32.0	32.6
West South Central	0.0	0.0	1.8	4.6	10.0	22.2	25.0	26.2	26.2	26.2	26.2	26.2
Mountain	0.0	0.0	0.0	0.3	0.3	2.0	2.3	5.0	5.0	10.7	12.5	12.5
Pacific	0.0	0.0	0.0	4.3	4.6	19.4	20.8	36.8	37.6	41.9	41.9	42.2
Total	0.0	2.3	24.5	41.5	79.0	161.0	204.0	232.4	233.2	243.3	247.4	259.5

Table 6A-4b. Total Logging Residue Supply Schedule by Census Regions
(in 1987 Dollars/Million Btu and Trillion Btu)

	1987$/Million Btu									
	3.250	3.318	3.792	4.266	4.334	4.740	4.876	5.214	5.417	5.688
Region	**Trillion Btu**									
New England	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.6	19.8	21.1
Middle Atlantic	19.6	19.6	19.6	19.6	19.6	19.6	19.6	20.2	20.4	21.8
East North Central	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.7	14.7	15.2
West North Central	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.3	8.3	8.6
South Atlantic	84.6	84.6	84.9	86.9	87.9	88.2	88.5	88.8	88.9	89.5
East South Central	32.6	32.6	32.6	37.0	37.8	38.6	39.9	40.0	40.0	40.1
West South Central	26.2	26.2	26.2	30.2	30.9	31.6	32.8	32.8	32.8	32.8
Mountain	12.5	12.5	12.5	12.5	12.5	12.5	12.7	12.7	13.5	13.5
Pacific	42.2	42.2	42.2	42.2	42.5	43.1	64.6	66.3	68.6	68.9
Total	259.5	259.5	259.8	270.2	273.0	275.3	299.8	303.3	306.8	311.5

The quantities are mapped from the U.S.F.S. regions to census divisions using the same matrix as for whole tree chips.

Mill Residues

Data on mill residue quantities are available from Forest Statistics of the United States, 1987 (Waddell, et al., 1989) and the USDA/FS (1990) publication. Mill residues are reported by the following wood categories: coarse wood, fine wood, and bark residues for 8 regions and 4 uses. The 4 mill residue uses are: *fiber, fuel, other,* and *not used.* The mill residue use categories *fuel* and *not used* are considered. *Fiber* and *other* are used in designated paper and pulp industries and therefore not considered as available wood resourse. It is arbitrarily assumed that 50 percent of the category *not used* is an available wood resource for all sectors.

For the use category *fuel*, 36 percent of coarse wood and 10 percent of fine and bark residues are available. The 10 percent availability of fine and bark residues represents the market share to noncaptive markets while the 36 percent availability of coarse wood is based on estimates by Skog (personal communication to Anthony Turhollow, November 24, 1994). Coarse wood is mainly used in the residential sector while fine and bark residues are consumed in the industrial, commercial, and electricity generating sector.

Prices for residues at the mill were obtained from Skog (personal communication to Anthony Turhollow, November 24, 1992). A cost component for the transportation of wood of $0.187 per million Btu is used, which is based on an assumed delivery distance of 20 miles using a cost of $0.14 per dry-ton (12 percent moisture) mile and 17 million Btu per dry ton.

Table 6A-5 shows the supply schedule for mill residues.

Table 6A-5. Mill Residues Available for Energy Use in Noncaptive Markets

		Quantity of Residues		Prices of Residues	
Census Region	Skog Region	Coarse	Fine and Bark	Coarse	Fine and Bark
		Trillion Btu		1987$/Million Btu	
New England	North	1.47	0.79	3.263	0.930
Middle Atlantic	North	1.52	0.82	3.263	0.930
East North Central	North	4.09	4.40	3.263	0.930
West North Central	North	2.51	2.82	3.263	0.930
South Atlantic	South	9.48	15.84	3.060	0.888
East South Central	South	1.70	9.89	3.060	0.888
West South Central	South	1.32	7.68	3.060	0.888
Mountain	West	1.63	6.40	2.793	0.863
Pacific	West	17.75	13.41	2.793	0.863
Total		41.48	62.05		

Other Wood

Other wood includes wood waste generated by the secondary forest products industry (e.g., furniture), construction debris, waste pallets, and demolition wastes and is a relatively small quantity in comparison to other sources of wood.

The quantities and prices for *other wood* are obtained from Skog (personal communication to Anthony Turhollow, December 1, 1992). Skog provides data for three divisions of the United States. The data were mapped from the three regions to census regions using 1990 population data. The total amount of other wood, 5.285 trillion Btu, is quite small in comparison to whole tree chipping or logging residues. The quantities of other wood available by census deivision are presented in Table 6A-6. The price in all census divisions is $20.71 per million Btu.

Table 6A-6. "Other Wood" Supplies by Census Division

Census Division	Trillion Btu	Census Division	Trillion Btu
New England	0.274	East South Central	0.211
Middle Atlantic	0.779	West South Central	0.371
East North Central	0.870	Mountain	0.469
West North Central	0.366	Pacific	1.287
South Atlantic	0.658	Total	5.285

SOURCES: Oak Ridge National Laboratory, "Data and Sources Biomass Supply", Draft " prepared for EIA under Contract No. DE-AC05-84OR21400, Oak Ridge, TN, June 27, 1993.

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MODEL INPUT: *WCABMEL*

DEFINITION: Available generating capacity [MW] in NERC region *RN* and year *T*.

The maximal generating capcity is determined by the maximal value in each regional supply curve and converted into MW using the performance characteristics of the wood technology, represented in the RFM.

SOURCES: Craig, K.R.; Mann, M.K.. 1993. Cost and Performance Analysis of Integrated Gasification Combined Cycle (IGCC) Power Systems Incorporating a Directly Heated Biomass Gasifier. Milestone Completion Report. NREL. December 1993.

<u>MODEL INPUT</u>: *WCCBMEL*

<u>DEFINITION</u>: Capital costs for electricity sector in Census division *R* in year *T*

WCCBMEL represents the capital cost for an advanced Wood Integrated Gasification Combined Cycle (IGCC) technology which is estimated to be commercially available in the year 2000. The cost estimates are based on a detailed analysis and performed by NREL.

<u>SOURCES</u>: Craig, K.R.; Mann, M.K.. 1993. Cost and Performance Analysis of Integrated Gasification Combined Cycle (IGCC) Power Systems Incorporating a Directly Heated Biomass Gasifier. Milestone Completion Report. NREL. December 1993.

<u>MODEL INPUT</u>: *WVCBMEL*

<u>DEFINITION</u>: Variable costs for wood electricity generation for the utility sector in NERC region RN in year *T*

Variable cost is model determined. It is a composite of two factors: 1) a constant factor accounting for operational maintenance expenses and 2) fuel cost. Since there is no vehicle to pass fuel cost to the ECP, the cost for wood is converted into mills per kWh and added as an additional variable O&M cost component. The constant factor is 8.94 mills/kWh.

<u>SOURCE</u>: Electric Power Research Institute, "Technical Assessment Guide", Vol. 1, Revision 7, EPRI TR-102276S, Palo Alto, CA, June 1993.

<u>MODEL INPUT</u>: *WOCBMEL*

<u>DEFINITION</u>: Fixed O&M costs for wood technology in NERC region RN and year T.

The fixed O&M cost are 84.69 [1987$/kW] according to the NREL source. It is assumed to be constant across all regions and for all years.

<u>SOURCE</u>: Craig, K.R.; Mann, M.K.. 1993. Cost and Performance Analysis of Integrated Gasification Combined Cycle (IGCC) Power Systems Incorporating a Directly Heated Biomass Gasifier. Milestone Completion Report. NREL. December 1993.

<u>MODEL INPUT</u>: *WCFBMEL*

<u>DEFINITION</u>: Capacity factor for the utility sector in NERC region RN in year *T*

Capacity factor is assumed to be constant for all years and all regions at a value of 0.8.

SOURCE: Craig, K.R.; Mann, M.K.. 1993. Cost and Performance Analysis of Integrated Gasification Combined Cycle (IGCC) Power Systems Incorporating a Directly Heated Biomass Gasifier. Milestone Completion Report. NREL. December 1993.

MODEL INPUT: *WHRBMEL*

DEFINITION: Heat rate for wood technology in NERC region RN in year *T*

The heat rate in the wood submodule represents a composite of two technolgies: 1) the existing direct fired or co-fired wood boilers and 2) the future advanced wood integrated gasification combined cycle (IGCC) technology estimated to be commercially available by the year 2000. Therefore the heat rate must reflect the transition from the existing and current wood technology to the advanced IGCC technology beginning with the year 2000. An early NEMS projection was used to calcualte capacity-weighted average heat rates. By the year 2010 a technology mix of 52 percent current and 48 percent of future technology is attained.

The heat rates for the individual wood technologies and those representing the technology mix are listed in Table 6A-7.

Table 6A-7. Heat Rate for Represented Wood Technologies

Year	Direct Fired Boiler	IGCC	Weighted Mix
	[BTU/kWh]	[BTU/kWh]	[BTU/kWh]
1990	13762	11045	13762
1991	13363	11023	13363
1992	12964	11002	12964
1993	12566	10981	12566
1994	12167	10960	12167
1995	11768	10939	11768
1996	11768	10753	11768
1997	11768	10567	11768
1998	11768	10380	11768
1999	11768	10194	11768
2000	11768	10008	11745
2001	11768	10008	11684
2002	11768	10008	11623
2003	11768	10008	11623
2004	11768	10008	11623
2005	11768	10008	11623
2006	11768	9803	11606
2007	11768	9597	11037
2008	11768	9392	10935
2009	11768	9186	10853
2010	11768	8981	10426

<u>SOURCE</u>: Biomass Power Gasification System, Technology Characterization, DOE, Office of Energy Efficiency and Renewable Energy, 3/17/1994.

Appendix 6-B: Mathematical Description

The following equation calculates the total energy consumption from all sectors and all regions in trillion Btu. It is assumed that 3 percent of the industrial consumption is in the noncaptive market.

$$QUCI = QBMEL_{R,T1} + QBMCM_{R,T1} + 0.03\ QBMIN_{R,T1} \qquad \textbf{(6B-1)}$$

where:

- $QUCI$ = Quantity of wood energy consumed in all sectors (trillion Btu);
- $QBMEL_{R,T1}$ = Quantity of wood consumed by utilities in Census division *R* in year *T1*;
- $QBMCM_{R,T1}$ = Quantity of wood consumed in the commercial sector in Census division *R* in year *T1*; and
- $QBMIN_{R,T1}$ = Quantity of wood consumed in the industrial sector in Census division *R* in year *T1*.

The Wood Submodule uses a scheme to do a linear interpolation between two steps on the supply curve to determine the price of *wood PUCI* given a quantity of *QUCI*. The interpolation is expressed as:

$$PUCI = PRWT_I + \left[\frac{QUCI - QWT_{R,I}}{QWT_{R,I+1} - QWT_{R,I}}\right] x\ (PRWT_{I+1} - PRWT_I) \qquad \textbf{(6B-2)}$$

where:

- $PUCI$ = Price of wood for all sectors, in dollars per million Btu;
- $PRWT_I$ = Price from the all-sector supply schedule for supply function step *I*;
- $QUCI$ = Quantity of wood consumed in all sectors in trillion Btu; and
- $QWT_{R,I}$ = Quantity of wood energy from the all-sector supply schedule supply function step *I* in Census division *R*.

For the commercial, industrial, and utility sectors, the sector supply prices $PBMCM_{R,T1}$, $PBMIN_{R,T1}$, and $PBMEL_{R,T1}$, are assigned the value of $PUCI$ in Equation (6B-2).

The price *PUCI* of wood is computed for each Census region. To apply *PUCI* to NERC regions a simple mapping approach is used. The lowest price of a Census region that overlaps with a given NERC region establishes the price in this NERC region. This approach is based on the assumption that the lowest price quantities of wood are consumed exclusively rather than the higher priced commodity. Mathematically, it is expressed as:

$$PWNR_{RN} = \min\left[PUCI_R\right] \quad \textit{for all} \quad CDTONR_{RN,R} \neq 0 \tag{6B-3}$$

where:

$PUCI$	=	Price of wood for all sectors, in dollars per million Btu evaluated for all Census regions *R*.
$PWNR_{RN}$	=	Price of wood for all sectors, in dollars per million Btu in NERC region *RN*.
$CDTONR_{RN,R}$	=	mapping matrix to map Census regions into NERC regions.

Since the wood submodule does not have a vehicle to pass fuel cost to the ECP module, the price *PWNR* of wood is converted into a variable O&M cost component and added to the constant variable cost factor. The conversion is expressed as:

$$WVCBMEL_{RN,T} = WVC_{RN,T} + PWNR_{RN,T} \cdot WHRBMEL_{RN,T} \cdot C_1 \tag{6B-4}$$

where:

$WVC_{RN,T}$	=	Constant variable O&M cost component (8.94 [mills/kWh]) in NERC region *RN* and year *T*.
$WHRBMEL_{RN,T}$	=	Heat rate for wood technology in NERC region *RN* and year *T*.
C_1	=	conversion factor to transform from $/MMBTU * BTU/hWh to mills/kWh

Appendix 6-C: Bibliography

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Appendix 6-D: Model Abstract

Model Name:
Wood Submodule.

Model Acronym:
None.

Description:

Most Recent Model Update:
November 1994.

Part of Another Model?:
The Wood Submodule is a component of the Renewable Fuels Module (RFM) of the National Energy Modeling System (NEMS).

Official Model Representative:
Roger Diedrich.

Documentation:

Archive Media and Installation Manual(s):

Energy System Described:
Non-captive wood supply and associated price.

Coverage:
USA.

Modeling Features:
Nine seperate regions.

Non-DOE Input Sources:

Computing Environment:

Independent Expert Reviews Conducted:
None.

Status of Evaluation Efforts by Sponsor:

Appendix 6-E: Data Quality and Estimation Processes

Derivation of the All-Sector Wood Supply Curve Logging Residue and Whole Tree Data

Data Sources and Methodology

Data for logging residue and whole tree supplies and prices were obtained from an unpublished manuscript entitled "Marginal Cost Supply Curves for Utilizing Forest Waste Wood in the United States", written for the United States Forest Service. The document was authored by McQuillan, Skog, Nagle, and Loveless, and was completed in 1984. The purpose of the study was to determine supply conditions for making use of "waste" wood, or that wood which is currently "unmerchantable", in each of the nine Forest Service Regions. This was done separately for hardwoods and softwoods.

Using 1976 inventory data and U.S.F.S. projections for 1990, 2010 and 2030, McQuillan, et al. estimated the available inventories of four different categories of waste wood: logging residues; rough, rotten, and salvable dead trees; excess sapling trees; and excess small pole trees. The major source of this information was the USDA Forest Service Resource Report No. 23, "An Analysis of the Timber Situation in the United States, 1952-2030" (1982). In order to estimate a single supply curve for each of the regions, the authors assumed that each of the four different waste wood types would be transformed into a single, homogeneous product: unbarked wood chips produced at the mill site.

For energy production purposes, wood chips can easily be treated as a homogeneous product. However, in the attempt to portray supply conditions as accurately as possible, it was decided to treat logging residues and whole tree supplies separately in the Wood Submodule. Supply conditions differ for these two waste wood types, as the supply of logging residues is mostly a function of logging operations, while the supply of whole trees depends largely on growing conditions. For the latter category, it was necessary to divide the McQuillan inventory estimates by twenty in order to approximate a sustainable harvest of whole chipping trees.

For each of the 18 "situations" (region and wood type, hard or soft), the McQuillan team divided the waste wood categories into four haul distance classes and three "slope/operability" classes, producing 156 cost strata. Costs for removal, transport and chipping of waste wood were based on data for U.S.F.S. Region 1, which were obtained from Richard R. Withycombe (1982), "Estimating Costs of Collecting and Transporting Forest Residues in the Northern Rocky Mountain Region." These extraction and haul costs were mapped to Regions 2 through 7 using data from "Report 5 of the Summary of Reports of Timber Sale Type, Stand Size, Site and Ownership" (1977, Fort Collins, Colorado); to Region 8 using data from Adams and Haynes (1980), "The 1980 Softwood Timber Assessment Market Model: Structure, Projections and Policy Simulations" and Plummer (1977), "Harvesting Cost Analysis, In: Logging Cost and

Production Analysis"; and to Region 9 using data from the Forest Service Handbook #2409-22, "Timber Appraisal Handbook".

Slope/operability classes include "feller/buncher" (representing 0-20 percent on-site slope), "crawler tractor" (20-40 percent slope), and "cable yard" (40+ percent slope). As haul distance (to the nearest mill) and slope increase, the cost of salvaging the wood increases rapidly. Accessibility by road is another major cost consideration; however, the authors assumed that a certain percentage of the resource was accessible on existing roads, and that new roads would not be built solely to access a source of waste wood. Ultimately, the wood classes described above were aggregated into discrete regional supply schedules and then combined to form a national total for both hardwoods and softwoods.

Data and Model Limitations

The authors noted that aggregating cost and availability conditions which can vary greatly among the thousands of potential sites to the national and even regional level is fraught with difficulties. These are compounded when projections of supply conditions are made over a number of years. Waste wood is defined as wood which is not currently "merchantable", that is, wood which is currently unutilized. The quantity of standing trees and logging residues that fall under this category in the future will depend on market conditions. As log prices increase and the availability of high-quality, old-growth timber decreases, minimum tree size and top size parameters will shrink, and second- and third-growth stands will be managed more intensively to maximize yields and make up for the loss of old-growth timber. These factors will serve to reduce the number of saplings, pole trees, and rough, rotten, and salvable dead trees available for chipping.

The most sensitive assumptions are those associated with removal and hauling costs. Some sensitivity analysis was performed for the "North Rocky Mountain" region, and this indicated that costs were very sensitive to changes in the haul distance and slope/operability parameters. Since the elasticities are very high, inaccuracies in the original data on which location and operability classifications were based could have a major effect on potential supply prices.

In addition to location and availability, the supply prices also depend heavily on technology assumptions. Improvements in on-site operating techniques could greatly increase the quantity of waste wood available for economic use, and improvements in chip-hauling technology could obviate the need for removal of waste wood to mills for chipping, further reducing production costs. Other equipment innovations are expected to occur within the next few decades, reducing costs and increasing the availability of salvageable waste wood.

Finally, the authors mentioned demand factors that may lead to a change in market conditions. For example, if pulp and paper production increases in importance relative to lumber and plywood, the supply of waste wood available for other uses may be reduced. Debarking, which is necessary for the manufacture of some products, is quite expensive and changes in the demand for those products could also have an effect on the waste wood supply conditions.