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Input Parameters for Leap and Analysis of the Model 22C Data Base

Leona Stewart
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INPUT PARAMETERS FOR LEAP AND ANALYSIS OF THE MODEL 22C DATA BASE

Leona Stewart* and Moshe Goldstein†

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*Currently on loan from the Los Alamos National Laboratory
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ABSTRACT

The input data for the Long-Term Energy Analysis Program (LEAP) employed by the Energy Information Administration for projections of long-term energy supply and demand in the United States have been studied and additional documentation provided. Particular emphasis has been placed on the LEAP Model 22C input data base, which was used in obtaining the output projections which appear in the 1978 Annual Report to Congress. Definitions, units, associated model parameters, and translation equations are given in detail. Many parameters were set to null values in Model 22C so as to 'turn off' certain complexities in LEAP; these parameters are listed in Appendix B along with parameters having constant values across all activities. The values of the parameters for each activity are tabulated along with the source upon which each parameter is based - and appropriate comments provided, where available. The structure of the data base is briefly outlined and an attempt made to categorize the parameters according to the methods employed for estimating the numerical values. Due to incomplete documentation and/or lack of specific parameter definitions, few of the input values could be traced and uniquely interpreted using the information provided in the primary and secondary sources. Input parameter choices were noted which led to output projections which are somewhat suspect. Other data problems encountered such as input errors and code overrides are summarized. Some of the input data were corrected and a "revised" base case was constructed. The output projections for this "revised" case are compared with the Model 22C output for the year 2020, for one of the ten sectors, the Transportation Sector. LEAP could be a very useful tool, especially so in the study of emerging technologies over long-time frames. The results summarized in this report could serve to improve the data base and the LEAP code and therefore enhance further projections of long-term energy supply and demand.

I. INTRODUCTION

A. Background

Decision Focus, Inc. (DFI) delivered a demonstration model of the Energy Economic Modeling System (EEMS) to the Office of Applied Analysis of the Energy Information Administration (EIA) in 1978. Although this model had been documented,[1] many changes had been incorporated into EEMS by the Long-Term Energy Analysis Division (LTEAD) before the 1978 EIA Annual Report to Congress[2] was prepared, and time did not permit detailed documentation of these changes. Led by John Pearson, LTEAD prepared an extensive data base which is required to run the LEAP code; for the 1978 report, this data base and version of the LEAP code is called Model 22C. A clear distinction between the code, LEAP,[3] and LEAP Model 22C, should always be kept in mind. The DFI document has since been updated[4] but this version was not available for the preparation of ARC78,[2] and does not correspond exactly to LEAP Model 22C.

B. Documentation of the Input Data Base for Model 22C

The documentation available for Model 22C exists in various reports. "Leap Network and Data Documentation - ARC 78"[5] is now available only in draft form. Computerized listings[6] were received by private communication from John Pearson of the EIA which give the FORTRAN name, the DFI definition number (if one exists), the name of the parameter, and an indication of the source of the value chosen, although several parameters do not appear in this list. The report[5] includes diagrams of the Network for Model 22C for the ten Sectors, which have 150 nodes or activities represented. One or more pages of descriptive information is found for each activity, the function of that activity, further information on a few

of the data sources, and occasional comments which place caveats on one or more of the parameters chosen.

Unfortunately, however, these descriptions are incomplete in that needed information is generally lacking on most of the parameters. The network diagrams, which have been updated in Ref. 7, are extremely useful in tracing the input-output flow of energy. The "Annotated Bibliography" containing 14 additional references to the LTEAD data sources is copied directly from Ref. 2 and therefore becomes References 8 through 21 in this report. Another report often used as a reference is simply listed as EPRI.[22]

Descriptions of the Model 22C data are provided in Ref. 5 where several pages are devoted to comments on the various parameters which appear as "major assumptions," initial conditions, capital parameters, operating parameters, curves for resources (not supplied), allocation and demand, and finally, numerical values of the GLOBAL parameters[23] employed. Occasionally, some information on the sources of the latter is given although many of those GLOBAL parameters are assigned null values in Model 22C.

The Model 22C network diagram is shown in Fig. 1, which is taken from Ref. 7. All ten sectors of the Model 22C network are shown in Ref. 7 as Figs. A-1 through A-9 with each activity clearly defined, therefore the reader is referred to this report for further details. Simply, four DEMAND sectors drive the resource supply to provide energy in usable form demanded by the customer. The major resources are coal, gas, oil, and uranium, although new technologies are introduced over the time frame of the model.

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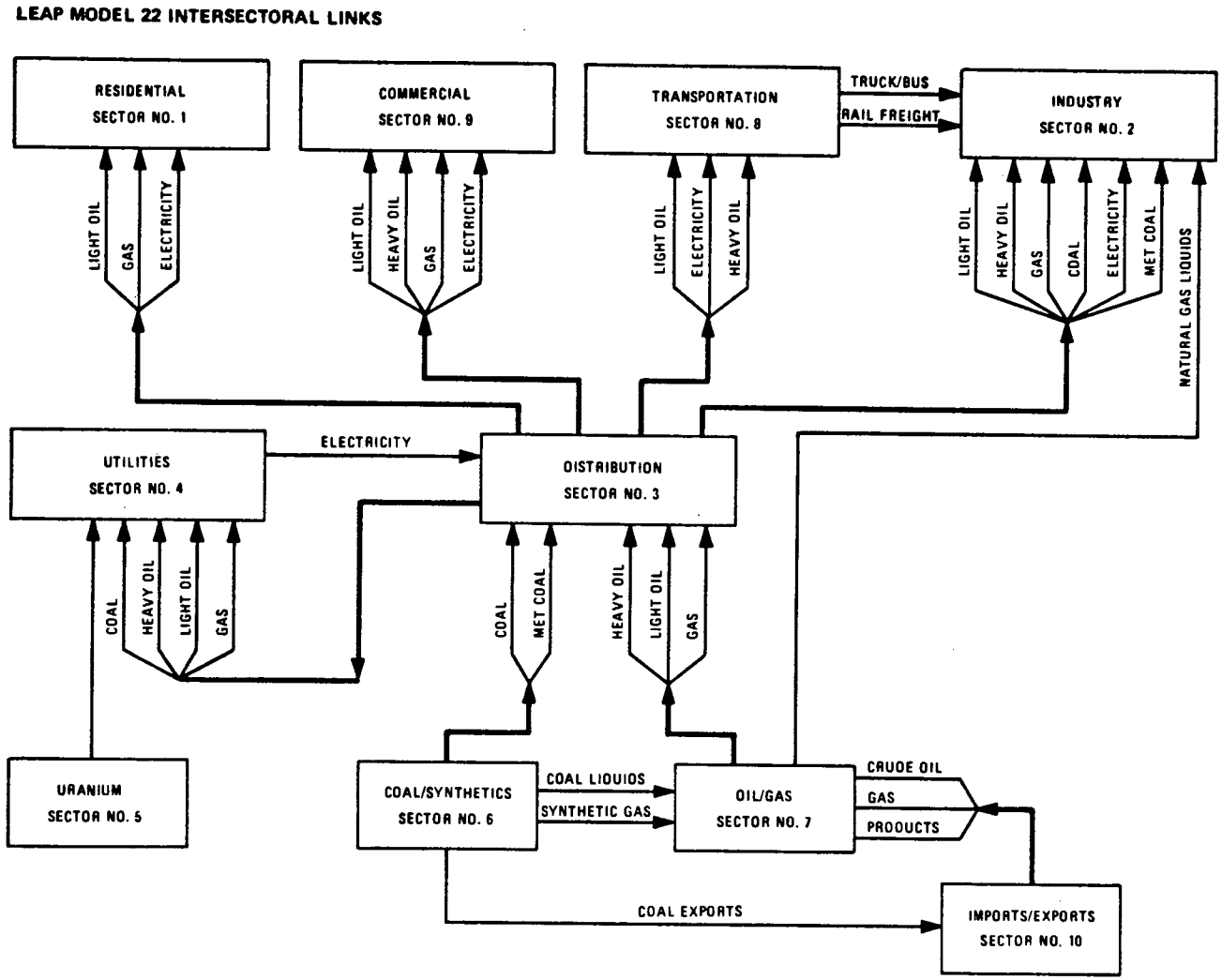

Fig. 1. Network diagram for Model 22C. (This figure was taken from Ref. 7).

C. Limitations in LEAP Which Affect the Model 22C Data Base

1. Regionality is not accounted for, except to a limited extent for gas, oil, and coal, since LEAP was designed for use as a national model. Much of the input data are based, however, on regional information and the methods used for aggregation were not described.
2. Many energy-related activities are not implemented in LEAP such as: retrofitting, environmental effects on prices or economic decisions as to whether to build the plant in the U.S. or abroad, feedback from the economic sector regarding the overall cost of present plants plus new additions (will the necessary supply of capital and appropriate labor be available?), tax incentives for switching to alternative energy sources, limitations due to siting, regulatory restraints, and a host of other complexities.
3. Some specific choices for individual parameters, which will be discussed in Section IV.

At first glance, one can ask what such problems have to do with the Model 22C Data Base for LEAP, but the modeler has often "adjusted" or "modified" one or more input parameters in a subtle way in order to attempt to "capture" a response which might have occurred if one or more of the above situations could have been handled directly as separate nodes or activities in LEAP. Therefore, such complexity introduced by the modeler makes the data base (and internal correlations among the values) much more difficult to analyze or compare with other sources of information in a straight-forward manner.

A point that must be borne in mind when using LEAP, and many other modeling codes,[7] is that energy demand is determined by the modeler for each model time point (every five years).* Supply is always equal to demand - therefore supply is also determined by the modeler. If one modeler assumes that a customer will use less energy in the year 2010, for example, than another modeler, then the problems associated with providing that energy to that same customer will certainly be less severe. The advantage in using LEAP is not the projection of energy supply and demand but the type of energy that can be supplied at a particular price, especially with respect to new technologies, when they come on line, and when they become significantly competitive. Therefore, it is important to emphasize the areas which discriminate between imported petroleum products and domestically produced synthetics which can be substituted in the market place.

D. Contents of This Report (Summary)

The structure of the data base is outlined briefly in the next section, followed by a description of the categories of the data sources. Problems with tracing the input values to their sources are discussed for selected data. In particular, specific input parameters in the residential, coal, transportation, and oil/gas sectors are described which bias the output or lead to projections that are not completely unambiguous. Other data problems encountered such as "code overrides" are briefly

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*The energy demand after 1995 in almost independent of the current model year price to the 1995 price, since the price elasticity parameter input to Model 22C is very small.

summarized. A "revised" base case is described and comments on the output projections are provided. Finally, conclusions and recommendations complete this report with the exception of the Appendices which are now described in detail.

The Appendices of this report represent additions and corrections to the documentation presently available for LEAP and Model 22C. The Appendices are separated into three parts:

Appendix A contains the definitions, units, FORTRAN name (if available), Model Parameter (and translation equations,* where necessary) for each input parameter. In addition, the relationship between the input parameter and the nomenclature used in the equations for LEAP[24] is given for each parameter, if they are not the same. Every effort was made to preserve compatibility with the LEAP code, the published Network Diagrams[7] and the published equations[24] to enable the user to follow the input parameters through the network, the subroutine logic, and the equations to the output calculations. Additional effort was required to differentiate between those parameters defined for the demonstration model† by DFI; those programmed for LEAP; those defined but not programmed; those defined but set to null values in Model 22C; and those re-programmed, added, or deleted by LTEAD. It should always be kept in mind that the Model 22C Data Base was used for the 1978 projections but that the LEAP code, itself, as maintained by LTEAD, is much more general in nature.

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*The input data parameter is "translated" by the code into the appropriate Model Parameter which has been implemented in LEAP (EMS). Therefore, when the two are specified differently, the translation equations are reproduced here as they appear in the FORTRAN program.

†These DFI documents[1,4] are the only references currently available which include the definitions, units, and translation equations to give the model parameters which are obtained from the input data. Of course, the latter are to be found in the FORTRAN program, itself.

The input parameters for Model 22C are separated into two lists which appear in Appendix A. In the first part, parameters A-1 through A-17 are defined. These parameters are not given in Chapter 7 of the DFI report,[4] although thirteen of the seventeen are described by LTEAD[5] in brief form, usually without the units defined. Since LTEAD carries the DFI parameter number in the input tables for LEAP Model 22C, the DFI numbering system[4] was preserved; therefore the parameters included in the DFI report,[7] numbered from 1 to 55, appear in the second part of Appendix A. Many corrections, additions, and deletions were necessary to insure compatibility with LEAP (1978 ARC Version) and, in many cases, with the DFI demonstration model[4] itself. The preparation of this Appendix was a significantly time-consuming task since changes were necessary on almost every page - and checks had to be made to determine whether corrections or changes had already been implemented by LTEAD[5] or by DFI[4] without updating the accompanying documentation.

Appendix B contains the values and sources used by LTEAD[5] in obtaining the GLOBAL parameters for Model 22C. GLOBAL parameters are defined as those parameters which are constant for all activities in all sectors (or almost all). Therefore, additions have been made to the list provided by LTEAD[5] by including those parameters which were set to null values in Model 22C.

Appendix C is a very complex listing of the many types of parameters (along with sources of the data) for each node used in Model 22C (some are null and have been omitted here). These nodes include processes such as conversion, allocation, demand, transport, resource

production, etc. The number of parameters are large, the uses vary with Sector or activity, and the sources are diverse. Therefore, no simplified method for presenting Appendix C could be determined. The sources for each input parameter were provided by LTEAD[6] in the form of computerized listings of the data. The additional LTEAD comments, which have sometimes been summarized for the sake of brevity, can be found in their entirety in Ref. 5. Therefore, the reader is cautioned to use Ref. 5, wherever possible, for the documentation which currently exists on the sources and their references.

In the preparation of Appendices B and C, it was hoped that a summary could be written, especially for C, which is so extensive in length and content. By the time the work was completed, however, it was decided that the data should be presented in their entirety, else useful information may be lost.

II. STRUCTURE OF THE MODEL 22C DATA BASE

In a study of the data base itself, it is important to know how the parameters are derived, whether they are knowable (that is, dictated by technology or history), the validity of the assumptions made, the importance of the parameters, (i.e., their impact on the output quantities and prices), the documentation of the sources employed, whether errors are introduced in the input, whether the code overrides the input value, the uncertainty estimates on the numerical values, whether the data can be traced to the original source, etc. In this work, it was found that many of the input parameters for Model 22C were set to null values which were not used in calculating the output projections. It should be borne in mind that although all input parameters are defined for LEAP's predecessor (EEMS)[4], they may not affect the output projections if the corresponding subroutine logic is not given in this version of LEAP; in addition, many parameters as chosen for Model 22C simply allow portions of the subroutine logic coded in LEAP to be bypassed. Every effort is made here to try to differentiate between results obtained with Model 22C and those which might have been obtained with different parameter choices using LEAP.

The parameters in Model 22C for the first model year (1975) were based on historical and technological data already available and therefore could be verified, when the necessary information* was provided (see, for example, Refs. 25 and 26). A few parameters are required by model year, that is, every five years from 1975 through 2020. Otherwise the model projections are driven by behavioral parameters which

*For example, the assumptions made for aggregation, etc.

dictate the market's response to prices and the customer's response to substitution among suppliers at the same or different prices. Market response characteristics are difficult to predict, difficult to model, and certainly difficult to validate.

A. Characterization of the Input Data

The main feature of LEAP is that the output quantity and price for all energy flows are driven by prices calculated within the model or entered by the modeler as, for example, the import prices for oil and gas. Energy is supplied to each activity within a sector according to the energy demanded for each model year. The LEAP output provides the particular type and quantity of resource demanded, and the conversion procedure for supplying that demand along with the price of each commodity.

A very general characterization of the data base can be summarized as follows:

1. Certain input data which are not used as numerical arguments to the final calculation of the model solution.
   a. Place holders, such as initial product prices, which are altered in the iterative process toward a solution.
   b. Parameters set equal to zeros or ones which act only as code operating parameters, such as Forecasting Perfection. (For example, when forecasting perfection is set equal to 1.0, as in Model 22C, the forecasting perfection block of code is automatically bypassed.)
   c. Parameters which are no longer implemented or not applicable such as the capital technological change rate. When the capital technological change limit is 1.0, a null value, the change rate is no longer implemented.

d. Input data for activities which are no longer implemented;* for example, solar heating as a separate activity in the residential sector is said in Ref. 5 to have been "dropped" from the program, Central Renewables in the utilities sector have been "constrained to predict 0.5 quad in the year 2020," and all explicit conservation activities have been "removed,"

e. Input that is held constant and equal to the output projections; for example, from the year 2000 to 2020, the electrical output from hydro-geothermal was assumed constant based on preliminary results of the National Energy Plan 2 (NEP-II).[15] See Note on Activity 4.18 (Hydro/Geothermal) at the bottom of Table C.4.c in Appendix C (Utilities Sector).

2. Those input parameters set directly or indirectly on the basis of output from other models:

   a. Data chosen so that Model 22C output in the mid term (1995) sill track the output of more detailed sectoral models,

   b. Data such as GNP growth rate taken from macroeconomic projections, and

   c. Resource projections.†

3. Those input parameters taken from historical data on the economy:

   a. Data on the energy balance in the initial model year (1975),

---

*How this is handled is not always clear since the input/output tables still exist. In some cases, the explanation has been found under another activity. For example, solar heating has been implemented by raising the efficiency limit on electric heaters from about 1.0 to 2.5 to account for heat pump technology and solar penetration in the residential sector. Quantities and prices are still calculated for the solar activity in the residential sector, however.

†The ARC-78 supply curve is set on the basis of systematic condensation of subjective judgements (USGS-725); i.e., no empirical model was used in the code.

b. Operating and capital costs for facilities of types that already exist, and
c. Past trends in financing that are assumed to continue into the future.

4. Engineering estimates for technologies not yet commercially available:
   a. Efficiencies and operating costs expected to be realized in new technologies, and
   b. Capital costs of new facilities based on 1975 costs for labor and materials.
5. Input parameters which attempt to "capture" economic behavior:
   a. Price elasticities of demand, and
   b. Behavioral lags in achieving economic efficiency.
6. Input data set directly on the basis of assumptions made for Model 22C.
   a. The prices of imported oil, gas, and oil products are input to LEAP throughout the time frame of the model with no restraints on total quantities. This is one of the major assumptions made for Model 22C.
   b. The quantities of metallurgical coal exported are set by the modelers.
   c. Hydro and geothermal contributions to elasticiity production are fixed input/output.

B. Ranges (or Bounds) on the Important Parameters for Model 22C

When this study was first initiated, screening theory was expected to provide a list of the Model 22C input parameters, ordered in importance. However, a pretest of screening methods now used in nuclear research showed these methods to be highly unreliable when applied to LEAP.

A program based on adjoint perturbation theory is underway to study the impact of the input data upon the output projections for LEAP. Although results are very preliminary at this time with only a few responses completed, this work is very encouraging. Many interesting output projections can be studied which could include: 1) the impact on the final energy bill, 2) the effect of reducing U.S. dependence upon foreign imports, 3) the importance of fuel switching (or substitution) in the market place, 4) the total number and type of facility which must be constructed in order to meet projected demand, and 5) the total capital investment required for new construction for each time frame of the model. Certainly, predictions of future prices and energy usage are important considerations, but the Congressman (and many of his constituents) may also be interested in knowing whether those energy facilities can be provided without significant disruptions in the present economic system consistent with current demands on important raw materials, capital supply and appropriate labor.

The above comments serve to emphasize the need to establish the list of important parameters and to determine the output projections which are of primary interest. For example, one parameter may be very important in reducing capital investment but not in reducing pollution; another parameter may be most important in reducing the price the consumer pays for energy but not the quantity of energy he uses, etc. Before these various responses are studied in great detail, however, the Model 22C Input Data should be corrected (where necessary) in order to be able to properly associate the output projections with the input data.

The Model 22C input parameters have been studied by Peelle et al. in Ref 7. In Table X-1 of that report, they provide approximate uncertainty estimates for a selected list of the input data.

III. DATA PROBLEMS IN LEAP MODEL 22C

Several problems were found in trying to understand the use of the Model 22C Data Base. Time did not permit an exhaustive study nor allow sensitivity runs to be made to assess the importance of the individual data parameters. Although some of these problems are not severe, all of those encountered are outlined here since this information may be important to a new user.

A. Behavioral Lag and Price Elasticity

These demand parameters (A-1 and A-2 in Appendix A) were added by the EIA. The following comments were taken from page xi of the DRAFT version[5] of "LEAP Model Network and Data-ARC78":

> "SENS Behavioral Lag (Demand) -- One minus the behavioral lag measures the rate of response of the economy to the long-term equilibrium position. The demand equation is a Koyck Transform Equation.
>
> ELAS Price Elasticity -- This parameter is the short-run elasticity, which measures the relative change in quantity with respect to the relative change in price. The resulting long-run elasticity (the short-run elasticity divided by one minus the behavioral lag) is -0.5, with a 50-percent response in four years."

The value chosen for SENS (Behavioral Lag) gives approximately a 50-percent response in 20 years rather than the four years quoted above. To achieve the desired long-run elasticity in four years, the input values for both of the above parameters should be changed. Applying the correction suggested in EPRI EA-433 Vol. 2 Appendix[22] would lead to:

SENS = 0.328 (instead of 0.8), and

ELAS = -0.336. (instead of -0.1).

This change gives the correct long-term elasticity, but one can argue about details of the best representation of a half-response time shorter than one period.

B. Facility Aging Rate (#23) VOAGRT

This input parameter is always overridden by the code in Model 22C. During the calculation of the aging multiplier for plant operation, the "steepness" parameter AGBETA (β_A) is set equal to 20 (instead of 1 or 2, expected) by the code due to the fact that the aging rate input parameter (VOAGRT) was entered as 3.0, while 0.03 (3% per year) is a more reasonable choice for a plant to age. (3.0 should have been entered as 0.03 in the data base.)

The pertinent input parameters and translation equations are reproduced below:

AGBETA (β_A) = (VOAGRT x ICLIFE)/(ℓn 2), where

VOAGRT (c) = the fractional increase in operating cost per unit of output per year (or fractional increase in operating I/O coefficient per year) when the age of the facility is equal to the characteristic facility life (in the absence of technological change),

ICLIFE (L_c) = the age of a facility at which the operating cost per unit of output is twice as great as when the facility was opened (neglecting technological change), and

L_A = the characteristic facility age.

The aging function $f_A(t)$ acts as a multiplier on all operating input/output coefficients of a plant. The functional form is

$$f_A(t) = \exp\left[(t/L_c)^{\beta_A}\right] ,$$

where t is the age of the plant. At t=0, the multiplier is 1.0; at $t = L_c$, the multiplier is "e". The parameter β_A describes the "steepness" of the function at $t = L_c$. As β_A increases, the function becomes steeper at $t = L_c$. Then,

$$\beta_A = \frac{c\ L_c}{\ell n\ 2}, \quad \text{and} \quad L_A = L_c/(\ell n\ 2)^{1/\beta_A}.$$

Since VOAGRT is a global parameter set equal to 3.0 for all activities, AGBETA was calculated to be greater than 20 for all processes. Therefore the LEAP code set AGBETA = 20 and the "intended" aging function is not used.

C. Transportation Sector Parameters

An error was probably made on the input to the Transportation Sector, which affected all the output projections for this sector. The variable operating cost excluding fuel (VOC) and the specific capital cost (SCC) appear to have been entered incorrectly into the data base so as to be 1/1000 of the values intended. The total operating cost, however, must include the fuel cost which is calculated using the efficiency parameters (EFF, AVEFF, and EFLIM) and these were entered correctly. This input error distorted the output prices calculated by the model.

Moreover, the total variable operating cost and the price enter into the calculation for the capacity factors and new capacity additions. The Model 22C results showed unusual variations in these quantities. For example, oil automobiles built in the year 2020 indicated capacity factors less than 8%; i.e., 42.35 units of new capacity were required to travel 3.23 trillion vehicle miles in the year 2020. Cars built before 2020 were driven only 0.12 trillion vehicle miles in order

to meet final demand. The average life of the automobile (characteristic facility life) is given as ten years in Model 22C.

The automobiles constructed in the year 2020 correspond to an efficiency of about 50 miles/gallon while the "fleet average" efficiency for 2020 is predicted to be 34.2 miles/gallon, notwithstanding the fact that 96% of the fleet was constructed in 2020. This "fleet average" corresponds to a car more than 15 years old but the output tables show those cars built prior to 2005 have already been retired. The Model 22C data therefore imply little correlation between the "fleet average" efficiency calculated by the model and the efficiency at the time the automobile on line was built.

The total demand for automobile vehicle miles is predicted to increase over the 1975 value by a factor of 2.35 by the year 2000 and more than a factor of three by 2020. It would be interesting to know how this increased demand is apportioned in terms of capital and operating costs, i.e., will three times as many cars be produced or will each car be driven three times the distance?[†] Even some combination would still imply significant demands on highway construction and maintenance in addition to the demands of the energy facilities themselves.

D. Capacity Factor Price Sensitivity (#37) CFSENS

This input parameter is used to calculate the model parameter, γ, which, in turn, appears in the capacity-factor equation. The equation for γ in the demonstration model (EEMS) is inconsistent with the definition for CFSENS although it has been carried over, unmodified, in LEAP. See p. A-51

[†]A method for extending the life of a facility or retrofitting is not modeled in 22C.

for complete details. An additional problem has been encountered since this parameter is reset to a value of 1.2 by LEAP if a lower value is entered. Although CFSENS is 1.34 in Model 22C, this override should be considered in the interpretation of direct-sensitivity runs.

E. Terminal Resource Multiplier (#53) TRMULT

This parameter is used during the calculation of the resource commitment multipliers on operation and maintenance cost (RCMTOM) and on capital cost (RCMTCC). If RCMTOM or RCMTCC is greater than 2 × TRMULT, then the final value is set equal to 2 × TRMULT. The effect is to assume an infinite supply of resource when price reaches this level.

F. Residential Sector Parameters

It appears that the choices made by the modeler for two parameters (FREQPR and EFLIM*) in the residential sector essentially forced electricity to become the major fuel used by the year 2000. This type of bias was probably not intentional since the choice of EFLIM resulted from an attempt to estimate a solar contribution to space heating,† which, when combined with the large values chosen for the shares at equal prices (FREQPR) for usage of electricity compound the effect.

Table C.1.a of Appendix C shows the large values assigned to FREQPR for electricity usage in all activities of the residential sector, and illustrates the curious fact that the shares at equal prices for oil

*EFLIM is the thermal efficiency limit which was assigned the value 2.5 for a purely resistive type electric space heater.

†The contribution from solar space heat is 0.001 quad in 2020 using Model 22C. LTEAD calculated a solar contribution exogeneously and then modified EFLIM here to account for the increase in space heat. See Table C.1.b in Appendix C and the comments which follow for full details.

(36.5%) are set a factor of four higher than for gas (9%), even though gas exceeds oil by far today.

The basic conversion parameters for the residential sector are given in Table C.1.b. (Appendix C). Note that the electric space and water heater (Activity 1.6) has an efficiency limit (EFLIM) of 2.5, which allows an increase to 2.39 with time of the efficiency of this "conventional" resistive heating unit. Technology dictates 1.0 as the maximum efficiency obtainable. The modelers comment that the 2.5 was chosen to "implement" a switch to the use of a "heat pump with solar backup" by the end of the model horizon by all customers. Unfortunately, however, there is no accompanying increase in the capital or operating cost for either the heat pump or the solar backup system, whether it be active or passive (CLIM = PRELIM = POSTLM = 1.0; that is all learning curves are bypassed). Note that the capital cost of the solar heater alone (Activity 1.5 in Table C.1.b) is set a factor of four higher than for the resistive type heater (Activity 1.6).

Therefore, it seems unlikely that reasonable changes in the other parameters chosen for this sector will significantly affect the output projections. Instead, a scenario could be designed using a homogeneous market (FREQPR the same), set EFLIM = 1.0 for the resistive type heater, and add a new activity which consists of a heat pump with electric back up - using more reasonably representative cost data. Results from such a scenario should be very informative for comparison purposes.

G. Oil/Gas Sector Parameters

In following the Oil/Gas Sector network diagram,* shown in Fig. 2, it was found that FREQPR, the shares at equal prices, showed no favoritism (that is, a homogeneous market was chosen) for the allocation of crude oil (Activity 7.3) and syncrude penetration (Activity 7.8) (see Table C.7.a of Appendix C for the data listings). At the top of the link, there are only two inputs to the refined oil allocation sectoral network (Activity 7.1) - domestic and imported. Since all oil is refined to some extent before it reaches the end user, refined oil is a particularly important allocation process. The share at equal prices for imported products† was set at 0.01% with the oil domestically refined equal to (1 - 0.0001) = 99.99%, since there are only two inputs to the process. With equal price shares, Model 22C would have predicted much more imported products in 1975 than actually occurred resulting from the assumption that the supply of imported products is unlimited, when in actuality the number of refineries in oil exporting countries is very limited. The shares used in Model 22C may fix the problem for 1975, but this choice led to a hidden assumption that new refineries will never be built in the exporting countries. The exporting countries, however, are already requesting that refineries be built within their territories within the next decade; refinery pollution controls in the U.S. are already very stringent; and the most efficient tankers are too

*Only the oil network of Sector 7 for Model 22C is illustrated here. The entire Oil/Gas Sector network diagram is shown in Fig. A-7 of Ref. 7 from which Fig. 2 is reproduced.

†According to LTEAD, this value was chosen to force the major imports to be crude oil. See Table C.7.a in Appendix C.

ORNL-DWG 80-7675R

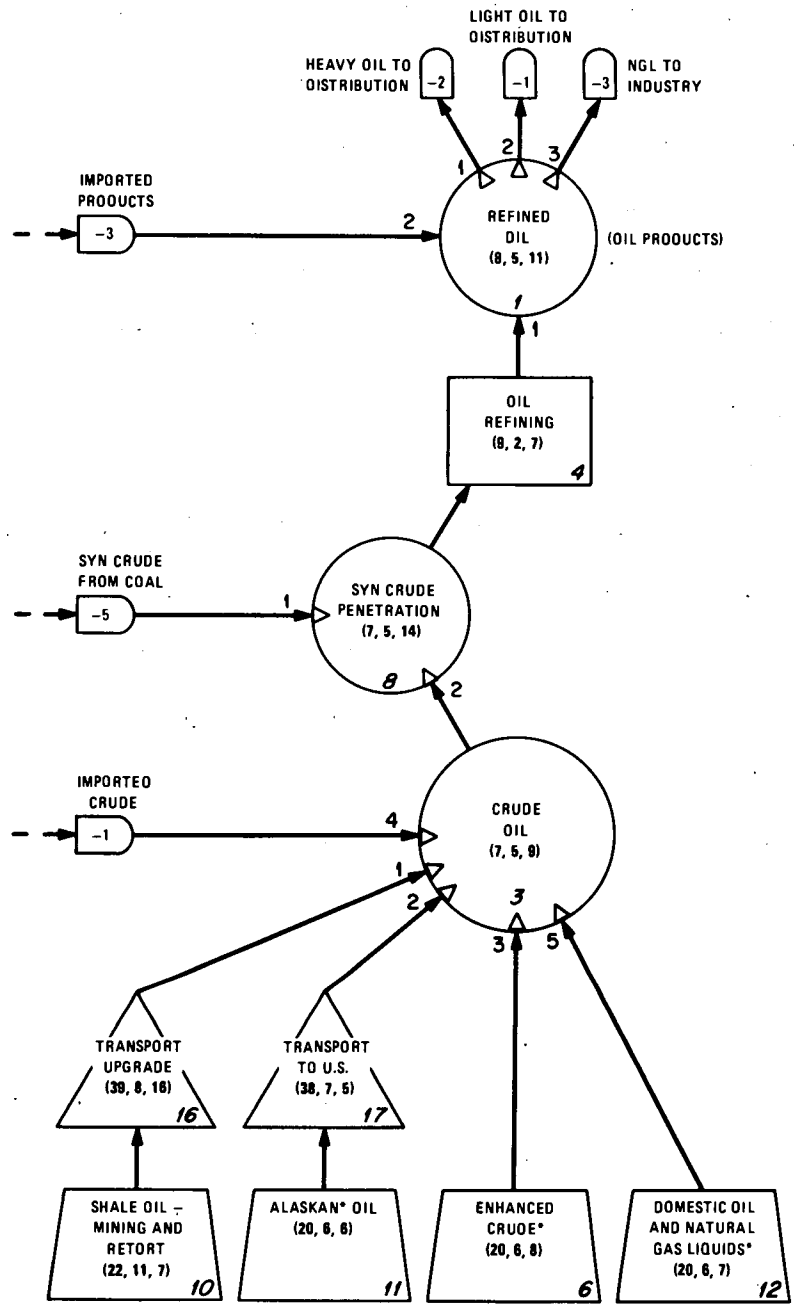

Fig. 2. Diagram of the oil network of the Oil/Gas Sector (#7) for Model 22C. This diagram was reproduced from Fig. A-7 of Ref. 7 which includes the complete network diagrams.

large to enter many U.S. ports where the oil is needed, thus causing refining elsewhere, reshipment, and higher costs.

If, as an alternative, we assume that exporting countries (like other actors in LEAP) will build capacity to produce as much as the market can absorb, we would use equal price shares to predict the 2020 market; the resulting predictions are very different as shown in Fig. 3.

Three runs were made increasing FREQPR to that of a homogeneous market (FREQPR = 50%). The results obtained for the year 2020 are shown in Fig. 3. Note that imported products increased significantly, mostly at the expense of synthetic coal liquids. Total liquids supply remained essentially constant at 38-39 quads, but oil from shale and EOR (enhanced oil recovery) both declined; total domestic products decreased from 31.4 to 23.5 quads while total imports (crude plus imported products) increased from 7.5 to 15.3 quads, all this, just from changing this one parameter alone. For comparison, about 12.3 quads of oil were imported in 1975.

The values quoted above are for a slow rate of response to prices which was used in Model 22C. The fast rate of response to prices drove imports much higher with further decreases in domestic production as shown in Fig. 3. This study therefore indicates that FREQPR, the shares at equal prices chosen for imported products, is a very importart parameter in the Model 22C input data in projecting reduced U.S. dependence upon foreign oil imports.

Another data problem has been attributed to the values chosen for the historical capacity additions change rate (RATIN, #31) for all resource processes in the Oil/Gas Sector. In particular, large peaks in

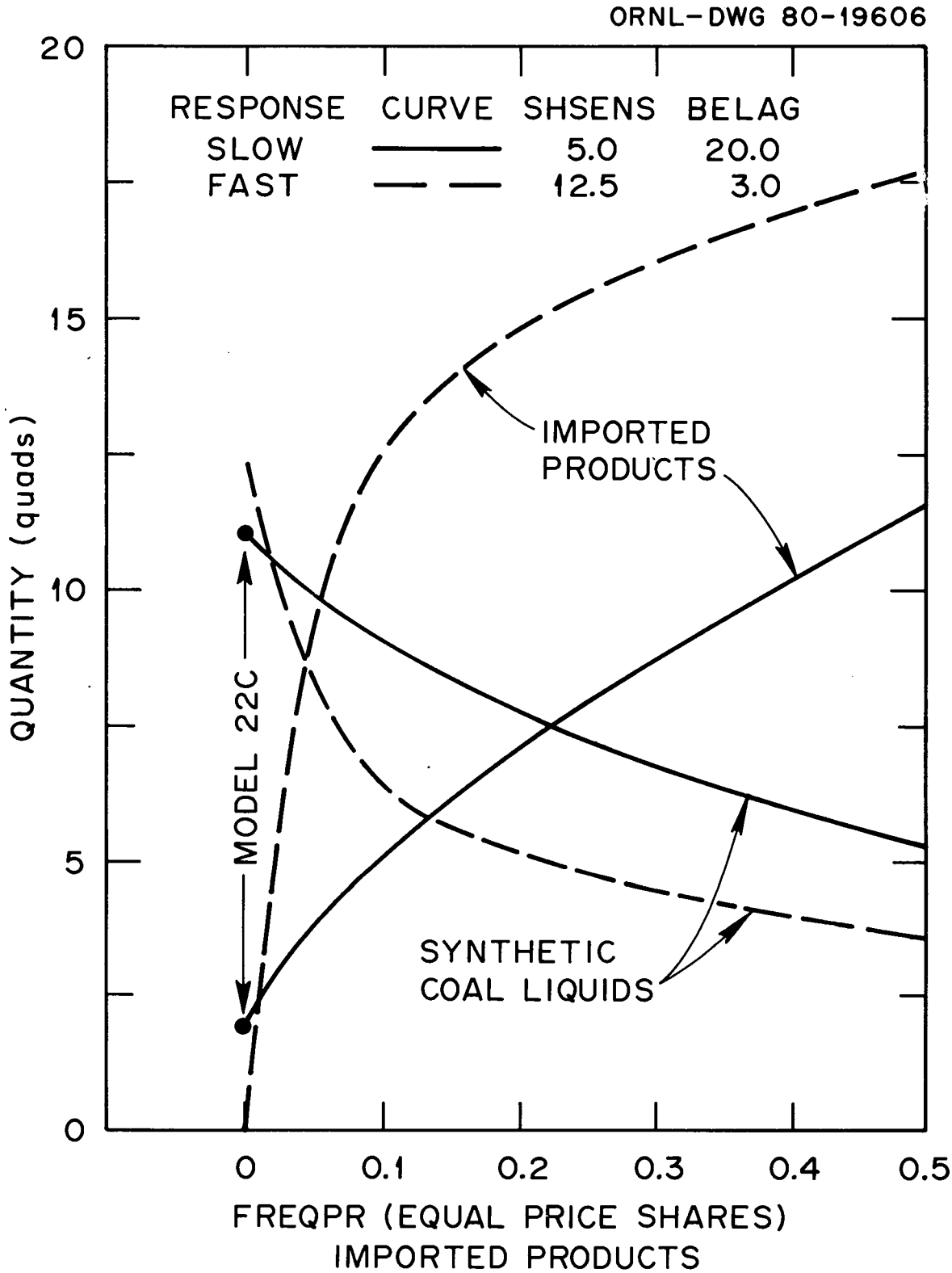

Fig. 3. Comparison of refined imports in the year 2020 with synthetic coal liquids (produced domestically) as the shares at equal prices for imported products (FREQPR) are increased to 50%. Domestically refined products have the shares at equal prices equal to (1 - FREQPR), since there are only two inputs to the link.

new capacity additions for the first model year (1975) were seen for domestic oil and gas production (Activities 7.12 and 7.14). With RATIN = 0.1998 in Model 22C, no new capacity came on line before 1975 even though the year of commercial availability is 1930 for oil and 1945 for gas production in the domestic market place.

H. Coal Sector Parameters

A similar problem occurred in the choice for RATIN, 1.0, used in the production of both medium and high sulfur western coal (Activities 6.16 and 6.23 in Table C.6.c of Appendix C). Again, no capacity came on line before 1975 even though the year of commercial availability is given as 1930 for both processes.

I. Link Differential (A-5) TRANSI

This is a link differential in cost which is added or subtracted in $/MMBtu for each time frame of the model. Unfortunately, it is a fixed cost, which does not change with time, therefore it is given in 1975$. This means that it would be impossible to implement an inflation rate not equal to zero unless LEAP is reprogrammed for the use of TRANSI.

IV. COMMENTS ON IMPORTANT INPUT PARAMETER CHOICES IN MODEL 22C

Several of the limitations in using the LEAP model are mentioned in the Introduction, although one must always bear in mind that economic and time constraints are serious deterrents in expanding an already complex code which requires further enlarging the extensive data base - and longer computer runs. It is hoped, however, that with time, a few improvements and modifications can be made. Basically, LEAP is a very useful tool which can help in the decision making process. The modelers are careful to point out that the projections made with LEAP are based on many assumptions, some of which are not easily testable. It is important, however, to note that the study here has not borne out the "expected" results - which are that user quantities are significantly constrained in response to higher prices.*

With these comments in mind, a few parameters are described which, if analyzed in detail, may lead to further insight into the output projections for LEAP.

A. Perfect Foresight

That the producer can predict the market value for all technologies and the consumer's response to substitution among suppliers with perfect foresight is an important assumption. Certainly, more caution need be exercised in investing in new technologies on a large scale, especially if the producer has no prior knowledge regarding pollution and regulatory constraints. More importantly, he would rarely have available technological data from an operating demonstration plant. Therefore, the

*See, for example, the results illustrated in Table 1 of Section VI.

parameters for mining coal may be predicted with better foresight than the production or use of a fuel cell of the future. Even for established industries, however, uncertainties regarding markets and suppliers are known to be very important, and may lead to far less use of coal,* for example, than predicted by cost-based models such as LEAP.

B. Resource Parameters

The dwindling domestic supply of oil and gas and the improbability that new reserves in significant quantities will be discovered dominate the problems of U.S. energy supply and demand today and far into the future. As these supplies are further depleted, they will increase in cost which, following the trends over the past decade, will be far in excess of that for other commodities. From the producer's point of view, his production costs will also increase as he drills deeper wells and/or extends further out in the ocean's depths. Therefore, one should question why the parameters:

49 HDCMLT	Half-Depletion Cost Multiplier
50 FDCMLT	Full-Depletion Cost Multiplier

were bypassed in Model 22C; and

45 UCCF	Undiscovered Capital Cost Fraction
46 NCCF	New Resources Capital Cost Fraction

were not programmed for LEAP. For example, oil shale becomes more expensive as the depth or grade of the deposit decreases.

For Model 22C, all inflation rates are zero and all costs are in 1975$ but energy (fuel) prices could well outstrip all other costs. Different resources could inflate in entirely different patterns, as

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*See for example the discussion on production constraints on coal, "Energy Future: Report of the Project at the Harvard Business School," Robert Stobaugh and Daniel X. Yergen, eds, Random House, New York, 1979, pp. 81 and 85. See also Ref. 27.

history has clearly shown by a comparison of oil and coal prices over the past decade.

The resource supply is projected by all modelers to change rapidly with time from direct use of oil and gas to indirect use of coal and uranium through the production of electricity and/or synthetic liquid fuels. Conversion losses are large; for example 30 Btu of coal produces only 10 Btu of electricity. Conversion losses for synthetic fuels are somewhat smaller but the problems inherent in getting rid of the additional waste and pollution could be significant deterrents in establishing new technologies, especially these involving significant quantities of coal.

As an example, total end-use consumption of energy in 1977 (Table 5.6 of Ref. 2) was only 60.2 quads (19.2 quads were lost in conversion). The projection for 2020 (Table 5.2) predicts total energy consumed to be 169.1 quads with 65.5 quads lost due to conversion processes. Therefore, in 2020, more energy is projected to be thrown away from conversion than this nation consumed in 1977. Pollution and waste problems significantly affect government regulations and market decisions today. While some problems can be modeled in LEAP, such as reforestation costs due to strip mining, others cannot. For example, the effects of acid rain on our future food supply* cannot be expressed simply by cost curves. As more and more energy is consumed, environmental restrictions could well surpass costs in determining the type of energy furnished the consumer of the future.

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*See for example, Ref. 27 and the January 1981 issue of Readers Digest, p. 109.

C. Import Prices for Oil and Gas

These prices are input by the modeler for each model year (See table C.10.a). The price of oil imports was assumed to rise to $30 per barrel (in 1978$) by the year 2000 and remain at that price through 2020. That such prices are much too low is already clearly evident. Therefore this point will not be belabored here.

D. Demand Parameters

The demand (or income) elasticities are tabulated and plotted in Appendix C for the four demand sectors in Model 22C as follows:

Sector 1.	Residential (Table C.1.c. and Figure C.1.)
Sector 2.	Industrial (Table C.2.c. and Figure C.2)
Sector 8.	Transportation (Table C.8.c and Figure C.8)
Sector 9.	Commercial (Table C.9.c and Figure C.9)

The detailed structure in these elasticities prior to the year 2000, which is especially dramatic for the industrial sector (Figure C.2), is difficult to comprehend since the total energy resources demanded and supplied over this time frame show little variation from smooth functions using Model 22C. That is oil, gas, and coal production show almost no structure. It is not possible, given the presently available documentation, to uniquely test the validity of these parameters.

The long-term demand elasticities are based on estimates of GNP and population growth rates in addition to assumptions on the rate at which GNP is absorbed in producing the energy demanded. These are smoothly extrapolated to 2020 from those predictions of the mid-term model.

E. Inflation Rate (historical and terminal); Assessed Value Inflator; Labor Cost; Material Cost; Capital Labor Fraction and Price Ceilings are not used

With these choices in Model 22C, the only way the total energy bill can be calculated for a given model year is to "assume" that all commodities in the market place inflate the same way; that is, no dependence upon different commodities, different suppliers, labor or materials etc. History has proven this to be incorrect and by a large margin. This assumption may be crucial to the output projections for new technologies.

F. Learning Curves

Changes in capital, operating, and fuel costs are allowed to change with time using so called "learning curves." These were rarely implemented in Model 22C except for fuel. That is, the technological change limits for capital, construction, and production were usually set to 1.0. Only in the Utilities and Coal Sectors were these changes occasionally implemented, as shown in Appendix C.

G. Efficiency (EFF) and Efficiency Limit (EFLIM); Importance in LEAP

Indications from the automobile market today imply that the customer's response to high efficiency may, in the long run, be more important than his response to high capital cost.* It is interesting, therefore, to understand the usage and choices made by the modeler for EFF and EFLIM in Model 22C.

The efficiency determines the fuel usage by that plant at the time it was built and that efficiency remains constant during its operating

*For example, many of the foreign imports are priced the same, if not higher than the U.S. model of the same or similar quality. On the average, however, they have a higher rating in miles/gallon and are already demanding a large share of the market.

lifetime. This means that a plant built at t_1 and one built at t_2 can have different efficiencies determined from the following so called "learning curve".

$$EFF(t) = EFF(t_0)[EFLIM + (1 - EFLIM)(1 - VOCRAT)^{t-t_0}]$$

where t is the time the plant was built and t_0 is the year of commercial availability or the first model year (1975 for Model 22C), whichever comes later. EFLIM is the maximum increase (or decrease) and VOCRAT is the rate at which the efficiency changes with time. This means, of course, that a car built in 1968 would operate with the same efficiency determined by the 1968 technology upon which it was based as long as it remains in the fleet of cars which are still operating, since retrofitting is not programmed in LEAP.

Consider the heat pump, as another example. Its efficiency depends upon many variables; it would certainly use much less energy in the same house if the house were better insulated. More importantly, however, its efficiency of operation directly depends upon the outside temperature; at low temperatures, the heat pump cannot operate at all; instead those backed by electricity become purely resistive heating units. In summer, the heat pump efficiency decreases as the outside temperature increases. This problem is easily summed up by concluding that during the highest demand periods, extreme cold in winter and extreme heat in summer, the heat pump would be operating at less than optimum efficiency (if at all) and these problems must be considered when assuming that all customers will switch to more efficient systems.

H. The Lack of Feedback and Accounting from the Economic and Materials Sectors

It is important to be able to determine the final energy bill, its relation to total GNP, the total capacity on line at each model time point, total capital investment in each technology and for each plant, and the cost of all new additions along with their capacity factors.

This type of information would be extremely useful in planning future expansions and in cutting back on capital spending. More importantly, however, it would enable the user to calculate how much steel imports would have to be increased to meet this particular building schedule and at what price.

Are the natural resources available (other than energy)? What is the ratio of energy spending to GNP? Even if the energy can be produced, can the autos and factories be built which use that energy? Photovoltaics is a good example to study. How much energy in Btu would it take to build the systems needed to capture 1% of the utility market in Btu in 10 years? What would be the capital cost? These are very important and interesting questions which need to be answered and could be addressed, at least in part, by using LEAP.

V. AUDIT TRAILS

A. General Comments

It was hoped that specific values of importance could be identified for the Model 22C Data Base and audit trails followed in detail. The time involved, however, became prohibitive therefore only a few useful results are described. The major problems encountered include:

1. Documentation provided was not complete; for example the report number is often missing; page number, table number or chapter number is always missing. (See Refs. 8 through 21.) This may mean wandering through a document that consists of many pages and looking for a number that was subsequently changed in an undocumented manner.
2. The document referenced is based on regional models and no attempt is made to describe the methods used in aggregating the results. In some instances, they were not aggregated at all but one region was chosen over another without justifying the choice.
3. The document referenced was prepared using a different sectoral network. That is, transportation may be in the residential sector, residential and commercial sectors are often combined in one sector, so they do not agree with the Model 22C Network.

4. Units of the parameters were not always provided, and sometimes the exponents, themselves, were questionable.
5. The value from a reference was "modified" in a manner not described.

B. Specific Examples

1. Allocation and Demand Parameters. No reasonable way could be found to audit these parameters although many are expected to be important.* The correlations between them may also be important.

2. GLOBAL Parameters. Few of the parameters which were implemented in Model 22C and listed in Appendix B could be traced to their sources. The comments provided are often incomplete but more importantly, perhaps, the proper documents were never located since the document number is often missing. Since all the information available to the authors is given in Appendix B, a summary is omitted here.

3. QUAN1Y (except transportation sector). These quantities could be checked for the first Model year (1975); see Refs. 25 and 26.

4. Initial Production (QUAN1Y) for the Transportation Sector. Since no exponents were provided for the units demanded in the transportation sector, the number of cars registered in 1975 was multiplied by 10,000 miles/year (average mileage driven, which was found to be reasonable) in order to determine that the input-output demand for miles was to be multiplied by 10^{12} (trillion). Comments which accompanied the data base state that the output is in miles or billion miles but nowhere could the

*See, for example, the discussion in Section III and Figure 3.

right exponent be found in the description for Model 22C. See, for example, Table C.8.c and the associated comments.

5. Specific Capital Cost of a Residential Gas Space and Water Heater. The specific capital cost used for Model 22C could not be verified since the definition was incomplete. The source used by LTEAD referenced earlier model data. Although all modelers for which their references could be found agreed that the specific capital cost for a gas space and water heater was about $500 to $600 (1975$), the data they input in their models varied by about a factor of six. Some included the duct work (omitting this cost for the air conditioning unit), the cost of the flue and its insulation, etc. Some chose the total energy demand from a high-load factor region while others chose low load-factor* regions. Just exactly what price would give the "correct" competition for capital investment among other heaters is not clear. As one example, the customer who is adding air conditioning to a home with a hot water heating system would be in trouble - since he does not have the duct work already installed.

6. Efficiency for Solar Heating in the Residential Sector.† A value of 4.0 is assigned by LTEAD with BNL[8] as the reference. This compares exactly with the value BNL used for solar heating in the residential and commercial sectors for the southernmost regions of the U.S. More importantly, however, Model 22C is supposed to have electrical backup (but

*The value chosen for Model 22C (see Table C.1.c) corresponds quite closely to the low-demand region for the combined residential and commercial sectors described in Ref. 8.

†The solar contribution in the residential sector is calculated as 0.001 quad using the Model 22C input data described herein.

electricity input to the network is not provided). Although the value of 4.0 checks exactly with the source in the audit trail, one should question whether this is the correct value when aggregated over all regions in the U.S. and also, how is the backup efficiency and energy obtained? Certainly, solar with electrical backup would require an efficiency less than 4.0 for any region in the U.S. since a "combined" efficiency is needed. One should also remember that, even in the midwest, the temperature occasionally drops below freezing.

7. Undiscovered Recoverable Resources. Two parameters are introduced in LEAP for the estimated quantities of resources which can be produced at base price (#42, UNRCRS) and at twice base price (#43, NEWRS2). For oil and gas, present estimates become more pessimistic with time, that is, the estimates made in 1978 are lower than those made in 1975. In LEAP, however, supply over the long term depends heavily upon improved and emerging technologies such as EOR, EGR, oil from shale and tar sands, etc. Therefore, the definition and use of these recoverable resource parameters become important and should be studied in more detail.

For example, a Department of Interior Report[28] lists 15,286 quads as the total nonrenewable energy reserves for North America. Unfortunately, only 301 quads are attributed to crude oil with about 14,000 quads estimated for oil shale, tar sands, and solid fuels (including coal); oil shale and tar sands dominate this estimated supply (about 9000 quads). Estimates for oil shale vary tremendously on a world-wide basis, however, from 1.1 to 16 $\times 10^{12}$ barrels, depending upon the source.[29,30] Many examples which indicate significant differences in estimates of energy available are to be found in the Energy Handbook[31] by Robert L. Loftness; several examples

are described in detail in a memorandum by Kurt Tech.[32] A problem is that undiscovered recoverable resources are not given (as they should be) as a function of extraction cost and minimum price of the material extracted.

VI. BRIEF COMPARISON OF RESULTS FOR "REVISED" MODEL 22C INPUT

One run was made with the input data base modified to reflect the values of some of the parameters which were presumably intended by the modelers; these are described below:*

A-1	SENS	Behavioral Lag; changed from 0.8 to 0.328
A-2	ELAS	Price Elasticity; changed from -0.1 to -0.336
23	VOAGRT	Facility Aging Rate; changed from 3.0/year to 3%/year
5	SCC	Specific Capital Cost; multiplied by 1000 in the Transportation Sector†
7	VOC	Variable Operating Cost (excluding fuel); multiplied by 1000 in the Transportation Sector†

Although time did not permit a detailed analysis of the importance and variation of each of the above parameters, a few points are briefly outlined here. First, the following responses are compared with the Base Case Model 22C when all five of the above parameters were changed at the same time:

1. End-use demand increased by about 4 quads in the 1995-2000 period with oil and gas accounting for most of the increase.
2. Total liquid fuels in the year 2000 increased from 38.5 to 40.7 quads.
3. Total gaseous fuels in the same year increased from 20.7 to 21.8 quads.
4. By 2020, imported oil and gas rose by about 1.6 quads.

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*CFSENS (#37) was not changed in this run since reprogramming is required in LEAP to include the dependence upon α.

†This method of correcting the Model 22C Data Base was suggested by LTEAD.

5. End effects (last year of the model time frame) were still observed but the deviations were less dramatic.
6. New capacity additions still showed large fluctuations which are not understood.

Table 1 shows the prices and quantities for 1975 compared to those predicted for 2020 for all nodes in the Transportation Sector. Three different runs were made: The Base Case in Model 22C; second, SCC and VOC (Specific Capital and Variable Operating Cost) in the transportation sector were multiplied by 1000, to account for the input error; and third, all five of the corrections listed above were made.

First, one should note that, except for the electric car, which became commercially available in the year 2000, the quantities show little response to prices. In fact, Truck/Bus mileage increased even though the price increased by a factor greater than sixty. Perhaps other errors in this sector are yet to be uncovered since the inconsistency between efficiencies of "fleet averages" and equipment efficiencies when placed on line still persists in the corrected run. For example:

The overall "fleet efficiency" for the gasoline and electrically powered automobiles decreased from 34.3 to 31.1 miles/gallon for the year 2020 in the "revised run" (3rd case). This "fleet average" car would have to be in operation for about 25 years to correspond to the efficiency it had the year it was built. Of some importance, perhaps, for the Model 22C Base Case run, about 96% of the cars on line in 2020 were built after the year 2015 with an efficiency approaching 50 miles/gallon. The method

TABLE 1

COMPARISON OF THE 1975 AND 2020 QUANTITIES AND PRICES
BEFORE AND AFTER CHANGES MADE TO THE MODEL 22C
DATA BASE FOR THE ACTIVITIES IN THE
TRANSPORTATION SECTOR

Proj. Year	Act. #	Description	Model 22C Quantity	Model 22C Price	SCC and VOC × 1000 Quantity	SCC and VOC × 1000 Price	Changed all Five Parameters Quantity	Changed all Five Parameters Price
1975	3.1.5	Light Oil	16.4	4.40	16.39	4.41	16.37	4.45
2020		(from Dist.)	18.8	7.45	18.9	7.46	19.06	7.65
1975	3.2.3	Heavy Oil	0.614	2.60	0.613	2.61	0.597	2.65
2020		(from Dist.)	2.26	5.65	2.41	5.65	2.38	5.85
1975	3.4.4	Electricity	0.0	10.20	0.0	10.21	0.0	10.26
2020		(from Dist.)	1.0(-5)*	11.92	0.073	11.93	0.674	12.12

Above quantities in Quads and Prices in $/MMBtu

1975	8.1	Aircraft	0.163	37.36	0.163	70.29	0.163	74.69
2020		Pas. Miles	0.309	43.44	0.314	75.23	0.307	80.99
1975	8.2	Auto-Oil	1.05	44.23	1.05	421	1.05	464
2020		Veh. Miles	3.35	23.25	3.12	397	3.02	434
1975	8.3	Truck/Bus	0.281	76.53	0.281	5331	0.281	6388
2020		Veh. Miles	0.469	81.2	0.484	5337	0.461	6614
1975	8.6	Auto-Elect.	0.0	640	0.0	3303	0.0	3633
2020		Veh. Miles	2.7(-6)*	56.35	0.015	473	0.138	476
1975	8.7	Rail/Barge	1.33	3.71	1.33	44.32	1.33	49.55
2020		Ton Miles	2.4	5.47	2.57	46.3	2.54	51.79

Above quantities are in trillion (10^{12}) miles.

Above prices for Model 22C have no meaning. The prices for the second and third cases are interpreted as $/1000 miles. This interpretation is consistent with the units chosen for the input efficiency, which is in miles/1000 Btu.

*Read as 1.0×10^{-5} and 2.7×10^{-6}, respectively.

for obtaining average fleet efficiency is not understood in terms of new capacity additions.

It should be noted in the corrected run, that the electric car came on line in the year 2000 (0.3 quad) and increased to 0.7 quad by 2015, then dropped slightly in 2020. This car did not penetrate the market at all using the Model 22C uncorrected data base. Using less pessimistic operating costs and efficiencies than those chosen for Model 22C may have allowed significant electric car penetration by 2020 (see Ref. 27 for an excellent thesis on this technology).

Some of the differences outlined above may be significant if one is trying to assess direct "sensitivity" to individual parameters. Whether the changes made have produced "additive" results or increases cancelled decreases is not known. It would be enlightening to "test" each parameter, one at a time, but such an exercise was not within the framework of this study. A listing of the RPORT output is available upon request for the "revised" run.

VII. RECOMMENDATIONS AND CONCLUSIONS

This study was primarily concerned with the following objectives: 1) to review and clarify the definitions for LEAP and the Model 22C Data Base; 2) to perform audit trails of a few important parameters; 3) to describe problem areas (if they exist) in using the Model 22C Data Base; 4) to identify the most important parameters for Model 22C; and 5) to assign ranges (or bounds) on the values of these important parameters.

Due to time constraints, all of the problems encountered could not be included but it is hoped that the sampling chosen for presentation in the previous sections will be useful in future work with LEAP. ORNL has not had the resources to assess all the many uncertainties involved in the thousands of individual numbers input to LEAP. Furthermore, prior to completion of the adjoint analysis,[33] there is no reliable basis for selecting the most important subset of these numbers for an evaluation of uncertainty.

The Appendices of this report were prepared to supplement the documentation presently available for LEAP and Model 22C. Tabular values are given for the input parameters along with their units, definitions, model parameters, translation equations (where necessary),[†] FORTRAN name (if available), the symbology used in the equations for LEAP[24] and the source upon which each parameter is based, if this could be found. The data in Appendix C cover many applications in LEAP such as conversion, allocation, demand, transport, and resource production processes, therefore the listings are very complex.

LEAP is a useful tool; it should be analyzed in more detail. This study has indicated that further investigation of the impact of the input

[†]These equations give the relationship between the input parameter and the model parameter where they are not the same.

data upon the output projections need be made before the Model 22C Data Base is widely accepted. Certainly, the corrections suggested here should be reviewed and implemented, where necessary, bearing in mind the problems in interpreting the output tables. Many of the difficulties briefly outlined here may have already been addressed in the 1979 and 1980 Annual Reports to Congress (see Refs. 34 and 35), but the input data upon which these later projections are based have not yet been studied. At the very least, the problems outlined here may be useful check points for later reports using LEAP.

It has always been assumed in making the ARC projections that the necessary energy facilities can and will be constructed in time to meet consumer demand. If a record were to be maintained of the total capacity and type which must be built to satisfy demand for each model year, this information could be correlated with or by other agencies (than the EIA) on siting, environmental pollution standards, etc. The total capital investment required for each model year would also be useful information.

Many difficulties were encountered in reading and interpreting the output tables for Model 22C. While some labels were obviously in error and inconsistencies were occasionally apparent, it was impossible to determine that each value was properly identified. Since these output tables are used in compiling the report to Congress,[2] some effort is recommended to ensure that these tables are correct and consistent.

It would certainly be worthwhile to make runs to test the magnitude of a few conservation efforts. For example, the price of additional insulation to a house could be added to the capital cost of the space heater (or cooler). This new activity could be added with increased

efficiency but all other costs the same. Then the customers' response to capital investment versus fuel cost could be determined in this way.

Although not exact, of course, several activities could be mocked up in similar fashion which would give reasonable estimates of the magnitude of the effects of some types of conservation efforts. If such processes are found not to be competitive, further study would not be required except in those cases where the necessary detail could not be included in this ad-hoc manner suggested.

It would be both useful and interesting to understand the behavior observed in the output projections after making the corrections outlined in this report in addition to a few other modifications to the Model 22C Data Base and to LEAP. A few selected scenarios are outlined below which are characterized as minimal requirements for addressing some very important issues. These scenarios are separated into short-range and long-range tests, where the latter requires recoding for LEAP.

A. Short-Range Tests

1. Check the corrections suggested in Section III.A to III.C.
   - Make the changes, one parameter at a time and analyze the output.
   - Insure that the units in Table C.8.b (Appendix C.) are correct; if not, provide the correct units, including the exponents.
   - Determine why the large changes in prices as seen in Table 1 (when the quantities are in miles) have no effect on prices or quantities (when the quantities are expressed in Btu).
   - Change CFSENS.
   - Change RATIN, where necessary.

2. Suggested revisions to other parameters.*

- Increase significantly the prices of oil and gas imports.
- Change FREQPR to reflect an homogeneous market for all activities in all sectors (see the discussion on the Oil/Gas Sector, Section III). Since FREQPR was often used as an ad-hoc parameter, this run should present comparative responses to purely competitive markets.
- Change EFLIM from 2.5 to 1.0 for the resistive type electric heater in the residential sector. Perhaps one can determine whether solar, gas, or oil will compete in a different manner.
- Test the effect of making the facility aging rate (VOAGRT) a variable among different activities; that is, should all facilities age at the same rate?
- Implement the parameters:

  HDCMLT - Half-Depletion Cost Multiplier

  FDCMLT - Full-Depletion Cost Multiplier
- Increase the efficiency of the electric car in the Transportation Sector by at least a factor of three.#
- Check to see if other parameters for the electric car should be changed.#

B. Long-Range Tests:†

1. No reprogramming necessary.

---

*The corrections outlined above should be maintained in these runs if deemed appropriate after review.

†The changes made for the short-range tests should be carried over for these long-range runs.

#See Ref. 27 for an excellent discussion regarding the electric car.

- Describe a heat pump (with electric backup*) as a new activity in the residential sector.
- Check to see if the parameters used for solar heating can be changed in a reasonable fashion.
- Check the significance of the structure observed in the demand elasticities before the year 2000 and compare total resources demanded.
- Make runs by reducing and increasing the demand elasticities by 10 and 20% to test their effect during the period 2000-2020.
- Make a few runs to determine order-of-magnitude effects of retrofitting costs, such as adding another scrubber to an existing power plant.
- Make a few runs to test conservation effects by increasing the efficiency of a heater (along with its capital cost) to mock up added improvements or additional insulation in the commercial sector.
- Attempt implementation of other learning curves where they are turned off in Model 22C; check a few cases.

2. Reprogramming Necessary (while maintaining the above changes)
   - Implement inflators and inflation rates $\neq 0.0$ and not equal the same for different commodities over different time frames of the model. (TRANSI, for example would have to be reprogrammed.)

---

*Solar backup could perhaps be used instead of electric but it may be prohibitive on the basis of total cost. More importantly, perhaps, solar backup alone would not be appropriate for colder climates, without some form of heat storage, which would again significantly increase the capital and operating costs.

- Implement in LEAP:

  UCCF - Undiscovered Capital Cost Fraction

  NCCF - New Resources Capital Cost Fraction

- Reprogram LEAP for the calculation of γ in the capacity factor (see pp. 18 and A-51 for details).

- Maintain and include in the output projections a record of every facility (plant, automobile, heater, etc.) constructed in each time period and the total capital investment. This record would enable the user to estimate the impact on the economy and to determine whether the necessary natural resources (copper, steel, etc.) can be supplied for energy program construction.

Although many useful scenarios are readily envisioned, analysis of the runs described above are recommended before significantly more complexity is introduced into LEAP. The total cost of energy (final energy bill) is useful and important information but the price of energy defines only a portion of the problem. Until new capacity additions and associated capital and operating costs are tabulated and studied as recommended above, useful information on the cost in money and materials and the real effect of the energy programs on the overall U.S. economy will still be missing.

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[30]Culbertson and Pitman, USGS Professional Paper 820.

[31]Robert L. Loftness, Energy Handbook. Van Nostrand Reinhold Company, New York, New York. 1978.

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APPENDIX A

NOMENCLATURE, DEFINITIONS, AND TRANSLATION EQUATIONS FOR THE INPUT PARAMETERS FOR LEAP

This Appendix contains the definitions and units for all the data parameters which the user must specify in order to run LEAP-EMS. For convenience, the first part of the Appendix (Section 1) contains a listing of the parameter names, ordered by parameter number, along with the assigned FORTRAN name (if a unique one is used in the code). This first section is then followed by another listing (Section 2) which is more complete in that the definition, units, and translation equations are provided where necessary to relate these input values with those implemented in the report[1] entitled "Specification of the Equations for LEAP Model 22C." Note that the symbology used in Ref. 1 is given on the first line in the right-hand corner along with the symbol as used in the equations, or, if different, a note to that effect is given at the bottom of the page for each parameter definition.

Note that this Appendix begins with parameters numbered A-1 through A-17, which were taken from Ref. 2. These parameters are additions to the list which do not appear in the DFI document;[3] several were added by the EIA to conform to changes made in LEAP-EMS, as mentioned in the Introduction. This list (A-1 - A-17) is then followed by another numbered from 1-55; the latter is the original DFI number system, which is preserved here since these numbers still appear in computer listings and other EIA documentation for LEAP.

The DFI parameters (1-55) are defined in Chapter 7 of Ref. 3. This Chapter has been rewritten with a few corrections, deletions, and comments added to provide better conformity with LEAP. It is useful to note that the parameters as defined and used throughout this report are also consistent with those implemented in Ref. 4, which gives the complete network diagrams for Model 22C.

All prices used in Model 22C are expressed in units of dollars for the initial model year, i.e., 1975.

APPENDIX A

Section 1

Parameter No.	Parameter Name	FORTRAN Name
A-1	Behavioral Lag (Demand)	SENS
A-2	Price Elasticity	ELAS
A-3	GNP (National Product) Growth Rates	GNP
A-4	Demand Elasticity (or Income Elasticity)	Y
A-5	Link Differential	TRANSI
A-6	Average Efficiency	AVEFFI
A-7	Return on Equity	ROE
A-8	Return on Debt	RDEBT
A-9	Price of Labor	PLI
A-10	Price of Material	PMI
A-11	Number of Global Time Points	NPOINT
A-12	Length of Each Time Period	DEL
A-13	Number of Short Periods per Long Period	NSHORT
A-14	Imported Crude Oil Prices	-
A-15	Imported Oil Prices	-
A-16	Imported Natural Gas Prices	-
A-17	Metallurgical Coal Exports	-

Parameter No.	Parameter Name	FORTRAN Name
1	Market Share Elasticity	SHSENS
2	Behavioral Lag	BELAG
3	Equal Price Shares	FREQPR
4	Initial Output Price	PRIC1Y
5	Specific Capital Cost	SCC
6	Capital Labor Fraction	CLFR
7	Variable Operating Cost	VOC
8	Operating Labor Fraction	OLFR
9	Thermal Efficiency	EFF
10	Planning Lead Time	IPLTIM
11	Capital Factor Lead Ratio	CFLDR
12	Year Commercially Available	IYRAVL
13	Pre-commercial Premium/Year	EARLY
14	Capital Technological Change Limit	CLIM
15	Initial Rate of Change	CRATE
16	Construction Time-Based Operating Technological Change Limit	PRELIM
17	Production Time-Based Operating Technological Change Limit	POSTLM
18	Operating Change Rate	VOCRAT
19	Thermal Efficiency Limit	EFLIM
20	Availability	AVAIL
21	Load Factor	LOADFC
22	Characteristic Facility Life	ICLIFE
23	Facility Aging Rate	VOAGRT

Parameter No.	Parameter Name	FORTRAN Name
24	Tax Depreciation Life	ITXLIF
25	Debt Life	IDLIFE
26	Income Tax Rate	INCTAX
27	Investment Tax Credit Rate	ITCRAT
28	Property Tax Rate	PTRATE
29	Equity Financing Fraction	EQFR
30	Initial Production	QUAN1Y
31	Historical Capacity Additions Change Rate	RATIN
32	Initial Additions Flexibility	NEWFLX
33	Forecasting Perfection	FORPER
34	Historical Inflation Rate	RINF(1)
35	Terminal Inflation Rate	RINF(2)
36	Capacity Factor Cost Multiplier	CFMULT
37	Capacity Factor Price-Sensitivity Parameter	CFSENS
38	Assessed Value Inflator	INFLAT
39	Fraction of Energy	ENFRC
40	Initial Resource Cost	INRCST
41	Base Price	BASEPR
42	Undiscovered Recoverable Resources	UNRCRS
43	New Resource at Doubled Price	NEWRS2
44	Current Capital Cost Fraction	CCCF
45	Undiscovered Capital Cost Fraction	UCCF
46	New Resources Capital Cost Fraction	NCCF
47	Deposit Decline Rate	DCLNO

Parameter No.	Parameter Name	FORTRAN Name
48	Owner Interest Rate	ROWN
49	Half-Depletion Cost Multiplier	HDCMLT
50	Full-Depletion Cost Multiplier	FDCMLT
51	Regulatory Policy	REGTST
52	Price Ceiling	REGPR
53	Terminal Resource Multiplier	TRMULT
54	Distance	DIST
55	Input-Output Coefficients	ROIO

APPENDIX A. Section 2.

A-1. Behavioral Lag (Demand) SENS ($S > 0$)

Def: The behavioral lag measures the relative change in demanded quantity with respect to the relative change in the previous model year demanded quantity.

Units: dimensionless

A-2. Price Elasticity ELAS ($E_L < 0$)

Def: The price elasticity is the short-run elasticity, which measures the relative change in quantity with respect to the relative change in price.

Units: dimensionless

- -

Interpretation: The resulting long-run elasticity (the short-run elasticity divided by one minus the behavioral lag) measures the rate of response of the economy to the long-term equilibrium position. The demand equation is a Koyck Transform Equation. (See Ref. 1).

A-3. GNP Growth Rates GNP Sectoral Index ⩾ 0)

Def: The annual percentage change in the gross national product in the U.S., averaged over each time period (Δ = 5 years) in the model. The value given for a time period is the average over the preceding 5-year period.

Units: percent/year (4.6% per year should be input as 4.6)

A-4. Demand Elasticity (or Income Elasticity) (Demand Sensitivity > 0)

Def: The demand elasticity is the rate of change in energy service demand with respect to the rate of change in GNP. Values are given for each of the four demand sectors (Residential, Industrial, Transportation, and Commercial) for each time period in the model.*

Units: dimensionless

- -

Usage: These paramaters are employed in the demand sectors for Model 22C, which are: Residential (#1), Industrial (#2), Transportation (#8), and Commercial (#9).

Note: The demand elasticity is also called the "income elasticity of demand."

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*It is stated that the population growth rates are also considered in deriving the demand elasticities which depend upon personal use and/or income, although the values are not provided by the modeler.

A-5. Link Differential TRANSI (T)
(no limit)

Def: The link differential represents an incremental price difference on the input(s) or output(s) of an allocation node. This parameter is often used where there is only one input - that is, no allocation process is affected.

Units: $/MMBtu

- -

Usage: TRANSI is often used to reflect:

a. Typical sources of market value differences such as quality, utility, economies of scale, competition, etc.,

b. Difference between retail and wholesale prices,

c. A transportation charge, and/or

d. A combination of the above.

Note: Not all allocation nodes require this input parameter. This parameter is a fixed input in $/MMBtu and therefore cannot be varied over the time frame of the model.

A-6. Average Efficiency AVEFFI ($E_{AV} > 0$)

Def: The average efficiency is defined as the average thermal efficiency from the year commercially available (AVAIL) to the first model year.*

Units: Same as EFF (Input Parameter # 9)

- -

Usage: (LEAP) E_{AV} appears in the equations for the learning multipliers used to calculate conversion processes (see, for example, Eq. II.20 of Ref. 1).

E_{AV} is also used to calculate r_s (parameter #31) for conversion processes. However, r_s is input directly for resource processes.

*How this value is obtained is rarely described for the Model 22C parameters.

A-7. Return on Equity ROE ($r_e \geqslant 0$)

Def: The return on equity is the required rate of return on equity funds invested. Input allowed for each model year in Model 22C.

Units: percent/year (5%/year would be input as 0.05)

A-8. Return on Debt RDEBT ($r_D \geqslant 0$)

Def: The return on debt is the interest rate on borrowed funds. Input allowed for each model year.

Units: percent/year (3% per year would be input as 0.03)

- -

Usage: ROE is used in calculating the minimum acceptable price on new facilities.

Note: In Model 22C, however, ROE and RDEBT are constant over the time frame of the model.

A-9. Price of Labor PLI $[P^{(1)} > 0]$

Def: The price of labor is a multiplier which represents the price of labor relative to the price at the first model year. Input is allowed for each model year.

Units: dimensionless

A-10. Price of Material PMI $[P^{(2)} > 0]$

Def: The price of material is a multiplier which represents the price of material relative to the price at the first model year. Input is allowed for each model year.

Units: dimensionless

- -

Note: PLI = PMI = 1.0 in Model 22C.

A-11. Number of Global Time Points NPOINT (N)

Def: The number of global time points included in the projection period, including the base year. Output projections are calculated at these time points.

Units: dimensionless

A-12. Length of Each Time Period DEL (Δ)

Def: The length of each time period (in years) between each pair of global time points.

Units: years

A-13. Number of Short Periods per Long Period NSHORT (NSHORT)

Def: The number of short periods per long period is the number of intervals in each time period (DEL).

Units: dimensionless

- -

Usage: NSHORT is used for the purpose of approximating time-varying discount rates. A value of one indicates that the discount rate is constant over the period.

Note: In LEAP, Model 22C, NSHORT = 1.

A-14. Imported Crude Oil Prices* ($P_I^{OIL} > 0$)

Def: The price of crude oil imported into the United States, input for each model year. The input price is the output price; that is, no iterations are performed on prices.

Units: $/MMBtu

A-15. Imported Oil Products Prices* ($P_I^{PROD} > 0$)

Def: The price of refined oil products imported into the United States, input for each model year. The input price is the output price, that is, no iterations are performed on prices.

Units: $/MMBtu

A-16. Imported Natural Gas Prices* ($P_I^{GAS} > 0$)

Def: The price of natural gas imported into the United States, input for each model year. The input price is the output price; that is, no iterations are performed on prices.

Units: $/MMBtu

- -

*In the LEAP Model, no restraints are placed on the quantities imported.

A-17. <u>Metallurgical Coal Export Quantities</u> ($Q \geqslant 0$)

Def: The quantity of metallurgical coal exported from the United States for each model year. These quantities are fixed input/output; that is, no iterations are performed on these quantities.

Units: Quadrillion Btu (Quads)

- -

1. Market Share Elasticity SHSENS ($\varepsilon \geqslant 0$)

Def: The percentage decrease in market share resulting from a one-percent increase in price when the market shares of all inputs are equal. Larger values of ε denote more competitive markets.

Units: dimensionless

- -

Model Parameter: Share Price Sensitivity GAMMA ($\gamma \geqslant \varepsilon$)

Units: dimensionless

Translation Equation:

$$\gamma = \frac{N}{N-1}\varepsilon ,$$ where N is the number of inputs to the market.*

Usage: GAMMA defines the static allocation of demand according to the following equations:

$$s_j = \frac{f_j \lambda_j^{-\gamma}}{\sum_{i=1}^{N} f_i \lambda_i^{-\gamma}} , \quad \text{and} \quad q_j = s_j q ,$$ where

s_j is the fraction of demand allocated to the jth source,

f_j is the value at s; at equal prices (see Def. # 3),

λ_j is the price of the jth source,

q_j is the level of demand allocated to the jth source, and

q is the total quantity demanded.

---

*If N = 1, the code sets $\gamma = \varepsilon$.

2. Behavioral Lag BELAG (BELAG $\geqslant$ 0)

Def: The behavioral lag is the period of time it would take before the market shares could make one-half of their ultimate readjustment to an instantaneous, one-time change in relative prices among sources.

Units: Number of years

- -

BETL (Model Parameter)

Units: dimensionless

Translation Equation:

$$BETL = 1 - 2^{-(1/BELAG)}, \quad \text{where}$$

BETL is the fraction of the remaining unadjusted market that will readjust in one year given the step change in prices.

Note: Nomenclature used in Ref. 1 (BETL = β).

3. Equal Price Shares FREQPR $(0 \leqslant f_j \leqslant 1)$

Def: The equal price share for the jth source is the fraction of demand allocated to the jth source if all sources offer the same price.

Units: dimensionless

- -

Model Parameter: same as above

Translation Equation: none

Interpretation: The equal price shares tell how the buyers will divide among competing sources when their decisions do not depend on price, i.e., all prices are equal. This incorporates all other non-price attributes of the sources.

Usage: The market share for the jth source is given by the equation:

$$s_j = \frac{f_j \lambda_j^{-\gamma}}{\sum_i f_i \lambda_i^{-\gamma}},$$

where f_j = equal price share for the jth source,

λ_j = price offered by the jth source,

γ = share price sensitivity parameter, and

s_j = fraction of total demand allocated to the jth source.

Range: In the current implementation of the model f_j is set equal to one divided by the number of sources unless the user specifies otherwise.

$$\sum_j f_j = 1$$

4. Initial Output Price PRIC1Y ($P_I > 0$)

Def: The initial output price for a process is the initial value for the output price in 1975, or the beginning model year. It may be changed during the iterative calculation toward the converged solution.

Units: $/MMBtu*

- -

Model Parameter: Same as the above.

Translation Equation: None.

Usage: PRIC1Y serves to determine the number of load categories for a conversion process; the number of load categories is equal to the number of values of PRIC1Y specified. [As used in the Utilitites Sector, three values of PRIC1Y are input to correspond to the three values of (QUAN1Y) which represent the initial production for base, intermediate, and peak load factors (LOADFC)].

Note: Since PRIC1Y is changed during the iterative calculation, it is not tabulated for each activity in Appendix C.

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*Except in the Transportation Sector for Model 22C. Due to an error in input parameters, the units for PRIC1Y are not defined.

5. Specific Capital Cost SCC ($S_c \geqslant 0$)

Def: $\frac{\text{Capital Cost of a Representative Facility}}{\text{Annual Capacity of a Representative Facility}}$, where the cost is for a plant put in operation in the initial model year or the year of commercial availability, whichever comes later.

Units: Energy Facilities - Reference year dollars/MMBtu/yr

Non-Energy Facilities - Reference year dollars/unit of capacity/year.*

---

6. Capital Labor Fraction CLFR ($0 \leqslant C_{LF} \leqslant 1$)

Def: The capital labor fraction is the fraction of specific capital cost arising from the labor used to construct a plant, excluding all labor costs embedded in the materials cost.

Units: dimensionless

Note: The fraction of specific capital cost arising from materials and other non-labor capital factors (capital materials fraction) used to construct a facility is equal to (1-CLFR) and thus does not need to be specified. The prices of labor and materials are expressed in reference year dollars and productivity levels which are normalized to 1.0. The user may specify any convenient reference year; prices generated by the model will be expressed in those same reference year dollars.

---

*In the Transportation Sector for Model 22C, the input values need be made consistent with the total operating cost.

CIO[1], CIO[2] (Model Parameters, where j=1 for labor and j=2 for materials)

Def: CIO[j] is the capital input/output coefficient given by

$$CIO[j] = \frac{\text{quantity of } j^{th} \text{ input factor}}{\text{quantity of capacity added}}$$

Translation Equations:

$$CIO[1] = SCC \times CLFR$$

$$CIO[2] = SCC \times (1 - CLFR)$$

Interpretation: A representative plant is specified in terms of its size and the technology upon which it is based. The following assumptions have been made:

- Capital cost includes land, plant facilities, auxiliary devices, off-site equipment, start-up costs, paid-up royalties, working capital, and contingencies as appropriate.
- Capital cost <u>excludes</u> interest during construction, investment tax credit, depreciation, inflation, and operating and maintenance cost.
- The nominal annual output from a representative plant is the nameplate capacity of the plant times its availability times the load factor at which it operates. We can think of availability times load factor as a "utilization" factor that tells how much the plant will actually produce relative to its capacity.
- Purchases of the jth capital factor are made one factor j lead time before the plant goes into operation and are expressed in reference year dollars.

Usage: The capital input/output coefficients derived from these inputs are adjusted over time by the technogical change equations as described in definitions 14 and 15.

Note: Nomenclature used in Ref. 1: $CIO[1] = b_1$
$CIO[2] = b_2$

7. Variable Operating Cost (Non-Fuel) VOC ($V_o \geq 0$)

Def: $$\frac{\text{Annual Non-Fuel Operating and Maintenance Cost of a Representative Facility}}{\text{Annual Output of a Representative Facility}}$$

where the cost is for the initial model year or the year of commercial availability, whichever comes later.

Units: Energy Facilities: Reference year dollars/MMBtu

Non-Energy Facilities: Reference year dollars/unit of output.*

---

8. Operating Labor Fraction OLFR ($0 \leq f_1 \leq 1$)

Def: The operating labor fraction is the fraction of variable operating cost arising from labor, excluding all labor costs embedded in the materials cost.

Units: dimensionless

Note: The fraction of the variable operating cost (operating materials fraction) arising from materials and other non-labor and non-fuel operating factors used to operate and maintain a facility is equal to $f_2 = (1 - \text{OLFR})$, and thus does not need to be specified. The prices of labor and materials are expressed in reference year dollars and productivity levels, which are normalized to 1.0.

- -

---

*In the Transportation Sector for Model 22C, the input values need be made consistent with the fuel cost.

OIO[1], OIO[2] Model Parameters, where j=1 for labor and j=2 for materials)

Def: OIO[j] is the capital input/output coefficient given by

$$OIO[j] = \frac{\text{operating cost of the quantity of } j^{th} \text{ input factor}}{\text{quantity of output}}$$

Translation Equations:

$$OIO[1] = VOC \times OLFR$$

$$OIO[2] = VOC \times (1 - OLFR)$$

Interpretation: As with specific capital cost, the variable operating cost is specified in terms of size and technology and presumes the following conditions hold:

- Annual operating and maintenance costs include total annual production expense less costs of primary fuels (plus any adjustment for by-products or other fuel inputs). Included are labor, overhead, utilities, royalties, excise taxes, fixed production expense, scheduled and unscheduled maintenance, and auxiliary device operating cost.
- Excluded are fuel, depreciation, interest, income taxes, property taxes, and insurance.

Usage: The operating input/output coefficients derived from these inputs are adjusted over time by the technological change equations described in definitions 16, 17, and 18.

9. Thermal Efficiency EFF ($T_{EF} > 0$)

Def: The thermal efficiency of a process is defined as:

$$\frac{\text{total energy content of product}}{\text{total energy content of primary input}}$$

for the initial model year or the year of commercial availability, whichever comes later.

Units: $\frac{\text{units in which process output is measured*}}{\text{units in which process input is measured}}$

E.g., if both output and input are measured in quadrillion Btu, thermal efficiency is dimensionless.

- -

OIO(3) (Model Parameter) is the operating input/output coefficient for fuel.

Translation Equation:

$$OIO(3) = \frac{1}{EFF}$$

Interpretation: The thermal efficiency of a process describes the energy usage in that process. The price of an energy product depends on the capital cost, operating cost, and thermal efficiency of the process that produces it.

Usage: The operating input/output coefficient for fuel at any time is equal to the base coefficient times a technological change multiplier (see definition #19).

---

*The efficiencies in the Transportation Sector were input in miles/1000 Btu in Model 22C, rather than miles/MMBtu.

10. Planning Lead Time IPLTIM (L ⩾ 0 and integer)

Def: The planning lead time is the length of time between the decision to build a plant and the time it begins production.

Units: years

- -

TCNSTR = Model Parameter = IPLTIM

Translation Equation: none

Interpretation: The planning lead time includes plant design, site selection, licensing, regulatory approval, environmental impact statements, and actual construction and start-up.

Usage: This parameter is the "from" point of all price forecasts made by a producer who is trying to decide whether to build a plant or not. He forecasts prices from that point on and, given those forecasts, he decides whether or not to build the plant.

11. Capital Factor Lead Ratio CFLDR (CFLDR $\geqslant$ 0)

Def: The capital factor lead ratio is the ratio of capital factor acquisition lead time LEAD (1) and LEAD (2) to planning time, IPLTIM.

Units: dimensionless

- -

LEAD(1), LEAD(2) Model Parameters

Def: Labor and Material lead times needed to construct new capacity.

Translation Equations:

LEAD(1) = CFLDR × IPLTIM (for labor)

LEAD(2) = LEAD(1) (for materials)

Usage: LEAD(i) is used in Subroutine IDC for calculating net present capital cost of a plant.

12. Year Commercially Available IYRAVL ($t_A > 1000$ and integer)

Def: The year commercially available is the first year a process can begin commercial scale operation.

Units: Years

---

13. Pre-commercial Premium/Year EARLY ($\rho \geqslant 0$)

Def: The pre-commercial premium/year is the fractional increase per year in capital and operating costs which must be paid in order to accelerate the availability date by one year. This premium is linear -- in order to introduce the process n years early, the fractional increase is assumed to be n times what it would be for one year.

Units: 1/years

- -

Model Parameters: Same as the above

Translation Equation: none

Interpretation: The year of commercial availability is the year that the private sector could begin to build an industry. It is not the year the first demonstration plant could be built.

For processes existing at the beginning of the model horizon, the year of commercial availability is defined to be the first year of the model horizon.

The effect of increased costs due to early introduction is modeled as an increase in the capital and operating I/O coefficients. The same multiplier is used for capital and operating factors:

$$f(t) = 1 + (t_A - t)\rho \qquad \begin{cases} t_A \geqslant t_G(1) \\ t_A \geqslant t \end{cases}$$

$$= 1 + \frac{2T_{EF} - 2E_{AV}}{0.8\ T_{EF}\ L_c}[t - t_G(1)] \qquad t_G(1) \geqslant t \geqslant t_A$$

$$= 1 + \frac{2T_{EF} - 2E_{AV}}{0.8\ T_{EF}\ L_c}[t_A - t_G(1)]$$

$$+ [t_A - t)\rho\ , \qquad t_G(1) \geqslant t_A \geqslant t$$

where,

$t_G(1)$ = first model year

T_{EF} = thermal efficiency (input parameter # 9)

E_{AV} = average efficiency (input parameter # A-6)

L_c = characteristic facility life (input parameter # 22)

t = year facility is built

t_A = year of commercial availability (parameter # 12)

ρ = pre-commercial premium per year (parameter # 13)

$f(t)$ = multiplier on capital and operating factors,

then,

$$CIO_j(t) = CIO_j(\text{base}) \times f(t) \qquad t < t_A$$

is the capital I/O coefficient if the technology is introduced before it is commercially available, and similarly for the operating I/O coefficients.

Usage: Year commercially available also affects the I/O coefficients for plants built after that date. See <u>Capital Technological Change Limit</u> and <u>Operating Technological Change Limit</u>.

14. Capital Technological Change Limit CLIM ($k_\infty > 0$)

Def: $\frac{\text{ultimate specific capital cost of a representative facility}}{\text{specific capital cost of facility in year it is commercially available}}$

Units: dimensionless

---

15. Initial Rate of Change CRATE ($0 \leqslant \beta_c \leqslant 1$)

Def: The initial rate of change is the fractional change per year in the specific capital cost in the year in which the technology associated with this facility becomes commercially available, divided by the total change expected (CLIM - 1); or equivalently, the fraction of total ultimate change that is achieved in the year immediately after the technology becomes commercially available.

Units: percent/year (3% per year would be input as 0.03)

Note: CRATE determines how quickly specific capital cost approaches its ultimate value. (Annual fractional change between I/O coefficient in year of availability and ultimate I/O coefficient.)

- -

Model Parameters: same as above

Translation Equations: none

Interpretation: This component of technological change specifies, over time, how much it costs to build a new facility of a given type. This type of "evolutionary" technological change could occur, for example, as plant designs improve over time.

Technological change is modeled by postulating a change over time in the specific capital cost of a facility. The two parameters CLIM (k_∞) and CRATE (β_c) determine a standard geometric learning curve:

$$f_c(t) = k_\infty + (1 - k_\infty)(1 - \beta_c)^{t-t_A} \qquad t > t_A \geqslant t_G(1)$$

$$= k_\infty + (1 - k_\infty)(1 - \beta_c)^{t-t_G(1)} \qquad \begin{cases} t > t_A \\ t_G(1) \geqslant t_A \end{cases}$$

$$= 1 + (t_A - t)\rho \qquad \begin{cases} t_A \geqslant t_G(1) \\ t_A \geqslant t \end{cases}$$

$$= k_\infty + (1 - k_\infty)(1 - \beta_c)^{t_A - t_G(1)} + [t_A + t_G(1)]\rho \qquad \begin{cases} t_A \leqslant t_G(1) \\ t_A \geqslant t \end{cases}$$

where,

t is the year the facility is built,

ρ is the pre-commercial premium per year,

t_A is the year in which the technology is first commercially available,

$t_G(1)$ is the first model year, and

$f_c(t)$ is the technological change multiplier for capital.

The capital input/output coefficient for the jth input for a facility constructed at time t is:

$CIO(j) \times f_c(t)$, where

CIO(j) is the base capital input/output coefficient for input j, as described by definitions 5 and 6.

16. Construction Time-Based Operating Technological Change Limit — PRELIM — ($g_{\infty\ell} > 0$)

Def: The construction time-based operating technological change limit is the ratio of the ultimate first year operating input-output coefficient for a fully mature technology (i.e., the input-output coefficient of the ultimate plant design for a particular technology) to the base operating input-output coefficient.

Units: dimensionless

---

17. Production Time-Based Operating Technological Change Limit — POSTLM — ($f_{\infty\ell} > 0$)

Def: The production time-based operating technological change limit is the ratio of the operating input-output coefficient after taking into account industry operating experience in terms of time since commercial availability of the technology to the base operating input-output coefficient.

Units: dimensionless

---

18. Operating Change Rate — VOCRAT — ($0 \leqslant \alpha_\ell = \gamma_\ell \leqslant 1$)

$\ell = 1,2,3$

Def: The operating change rate is the fractional change per year in each of these multipliers* in the year in which the technology becomes commercially available divided by the total change anticipated, which is just one less than the corresponding limit, or equivalently, the fraction of total ultimate change that is achieved in the year immediately after the technology becomes commercially available.

Units: percent/year (10% per year would be input as 0.10)

- -

---

*VOCRAT is also used in the learning multiplier for fuel (see Def. # 19).

Model Parameters: Definitions and Translation Equations:

OPNLIM(j) = PRELIM for input factor j (all j)

PROLIM(j) = POSTLM for input factor j (j=1 and j=2)

(for j=3, see Def. # 19)

OMRATE = VOCRAT , where

VOCRAT determines how quickly the input-output coefficients for operating factors approach their ultimate values.

Interpretation: This is the component of technological change which indicates how the operating cost of a plant changes over time. Part of this change depends on when the plant was built, e.g., the thermal efficiency of the process it uses or the amount of maintenance required (new plant configurations may require less maintenance). Part of the change depends on the time of operation of the plant, e.g., the labor force may become more skilled over time so that less labor is required per unit of output.

This technological change is modeled by postulating a change over time in the operating input-output coefficients of the plant. Thus, if OIO(j) is the base operating factor input-output coefficient for factor j, then the input-output coefficient at time t is

$$OIO(j)\ f_c(j,\tau)\ f_0(j,t)$$

where τ is the time of construction and c denotes construction, 0 denotes operation. Each of these mutlipliers has the same functional form as the multiplier for the capital input-output coefficient:

$$f_c(j,\tau) = g_{\infty\ell} + (1 - g_{\infty\ell})(1 - \gamma_\ell)^{\tau - t_A} \qquad \tau \geqslant t_A$$

and

$$f_0(j,t) = f_{\infty\ell} + (1 - f_{\infty\ell})(1 - \alpha_\ell)^{t - t_A} \qquad t \geqslant t_A$$

where,

t_A is the year of commercial availability or the first model year, whichever comes later (see Def. # 12).

Usage: The final value of each operating input-output coefficient is given by multiplying the base input-output coefficient times the two technological change multipliers discussed here times the aging multiplier discussed under the parameters Characteristic Facility Life and Facility Aging Rate.

19. <u>Thermal Efficiency Limit</u> <u>EFLIM</u> (EFLIM > 0)

Def: The <u>thermal efficiency limit</u> is the ratio of the thermal efficiency (for fuel) to the initial efficiency at the year of commercial availability, or the first model year, whichever comes later.

Units: dimensionless

- -

Model Parameter and Translation Equation:

The learning multiplier for fuel is written:

$$f_{03} = \text{EFLIM} + (1-\text{EFLIM})(1-\gamma_\ell)^{t-t_A} \quad , \quad t \geqslant t_A \geqslant t_G(1)$$

$$= \text{EFLIM} + (1-\text{EFLIM})(1-\gamma_\ell)^{t-t_G(1)} \quad , \quad t \geqslant t_G(1) \geqslant t_A$$

$$= 1 + (t_A - t)\rho \quad , \quad \begin{cases} t_A \geqslant t_G(1) \\ t_A \geqslant t \end{cases}$$

$$= 1 + \frac{2T_{EF} - 2E_{AV}}{0.8\ T_{EF}\ L_c}\,[t-t_G(1)] \quad , \quad t_G(1) \geqslant t \geqslant t_A$$

$$= 1 + \frac{2T_{EF} - 2E_{AV}}{0.8\ T_{EF}\ L_c}\,[t_A-t_G(1)] + [t_A-t]\rho \quad , \quad t_G(1) \geqslant t_A \geqslant t$$

where,

t = year the facility is built,

t_A = year of commercial availability,

$t_G(1)$ = first model year,

ρ = pre-commercial premium per year

T_{EF} = thermal efficiency (input parameter # 9)

E_{AV} = average efficiency (input parameter # A-6)

L_c = characteristic facility life (input parameter # 22)

γ_ℓ = the operating change rate (VOCRAT)* parameter # 18

*Model Parameter for VOCRAT is OMRATE.

20. Availability AVAIL $(0 < r_i \leq 1)$

Def: The availability is the fraction of demand that the plant can actually satisfy considering scheduled and unscheduled downtime.

Units: dimensionless

---

21. Load Factor LOADFC or LOADFE(I) $(0 < L_{fi} \leq 1)$

Def: The load factor is the fraction of time that a demand is placed upon a production facility.

Units: dimensionless

- -

Model Parameters: Same as above.

Model Definition:

Load Factor (I) = LOADFE(I) = I^{th} load factor

Availability = AVAIL = availability of a plant facing demands with load factors I.

Multiple load factors are used only for processes where the time varying nature of demand is modeled, e.g., electric power generation processes, where base, intermediate, and peak load factors are input.

Note: LOADFC has no argument. In the Utility Sector, however, LOADFC becomes LOADFE(I) where I represents base, intermediate, and peak load factors.

Translation Equations: none

Inter-pretation: Even for prices very high relative to variable cost, a plant trying to satisfy a demand at load factor [LOADFC(I)] will only be able to produce at LOADFC(I) × AVAIL(I) of the name-plate capacity; this gives the maximum capacity factor.

Usage: These quantities are used in two ways -- one for basic conversion and one for electric power. In the case of basic conversion, the load factor is unity and the availability is set equal to the plant stream factor. For electric power, the load duration curve is broken up into N discrete load factors. The Ith load factor is the percentage of time the Ith category that a representative plant can satisfy. Load factor, then, is a demand-driven parameter while availability is a plant-driven parameter.

22. Characteristic Facility Life ICLIFE ($L_c > 0$ and integer)

Def: The characteristic facility life is the age of a facility at which the operating cost per unit of output is twice as great as when the facility was opened (neglecting technological change).

Units: years

---

23. Facility Aging Rate VOAGRT ($0 < VOAGRT < 1$)

The facility aging rate is the fractional increase per year in operating cost per unit of output (or fractional increase in operating I/O coefficient per year) when the age of the facility is exactly equal to the characteristic facility life (in the absence of technological change).

Units: percent/year (3% per year would be input as 0.03)

- -

Model Parameter: AGBETA (β_A), which is the "steepness" parameter of the aging function.

Translation Equation:

$$\beta_A = c\, L_c/(\ell n\ 2), \quad \text{where } L_A = L_c/(\ell n\ 2)^{1/\beta_A},$$

L_c = the characteristic facility life (ICLIFE),

c = the facility aging rate at L_c (VOAGRT), and

L_A = the characteristic facility age (AGCHAR or TCHAR).*

---

*AGCHAR and TCHAR are the same in the present model.

Interpretation: One reason existing plants become economically obsolete (i.e., too expensive to operate) is that they tend to age, wear out, require more maintenance, become inefficient and so forth. This can be thought of in terms of the plant requiring more units of input per unit of output as it ages.

The aging function $f_A(t)$ acts as a multiplier on all operating input/output coefficients of a plant. The functional form is:

$$f_A(t) = \exp\left[(t/L_c)^{\beta_A}\right],$$

where t is the age of the plant. At t=0, the multiplier is 1.0; at $t=L_c$, the multiplier is "e". The parameter β_A describes the "steepness" of the function at $t=L_c$. As β_A increases, the function becomes steeper at $t=L_c$.

Usage: The operating I/O coefficients are adjusted by this aging multiplier. Thus, different ages of plants will have different I/O coefficients, even if there is no technological change.

24. Tax Depreciation Life ITXLIF ($T_L > 0$ and integer)

Def: The tax depreciation life of a facility is the time over which original facility investment is depreciated (using the double declining balance method) for tax purposes.

Units: years

- -

Model Parameter: TAXLIF (same definition as above) (T_L)

Translation Equation: none

Usage: Assuming that we have invested and capitalized $1, the allowable depreciation expense at the end of the first year is $(2/T_L)$; and at the end of the second year is $(2/T_L)(1-2/T_L)$; . . .; the allowable depreciation expense at the end of the kth year is:

$$(2/T_L)(1 - 2/T_L)^{k-1} .$$

Interpretation: In effect, a tax "credit" arises as a result of expensing depreciation for tax purposes. This has the effect of lowering the present value of capital investment. The tax depreciation life is specified partly by IRS guidelines and partly by negotiation between the producer and the IRS.

25. Debt Life IDLIFE (D > 0 and integer)

Def: Debt Life is the term on long-term corporate debt.

Units: years

- -

Model Parameter: D (Same definition as above)

Translation Equation: none

Interpretation: Financing of capital expenditures for new capacity is split between equity and debt financing. Debt financing takes place via issue of corporate bonds or by borrowing from a financial institution. In either case, the term and interest rate are set in advance.

Usage: The debt life parameter is used to calculate the present value of interest payments (including the tax credit due to expensing interest for income tax purposes) plus the present value of principal repayments.

26. Income Tax Rate INCTAX ($0 \leq f_T \leq 1$)

Def: The income tax rate is the effective state plus federal income tax rate.

Units: percent/year (10% per year would be input as 0.1)

---

27. Investment Tax Credit Rate ITCRAT ($0 \leq I_{tcr} \leq 1$)

Def: The investment tax credit rate is the IRS allowed investment tax credit rate on new investment. It is assumed that it can be completely taken by the producing firm as soon as it is earned.

Units: percent/year (10% per year would be input as 0.1)

---

28. Property Tax Rate PTRATE ($0 \leq P_{rt} \leq 1$)

Def: The property tax rate is the percent per year per dollar of assessed value that accrues to local governments in the form of property taxes.

Units: percent/year (10% per year would be input as 0.1)

- -

Model Parameters: same as above

Translation Equations: none

Interpretation: These annual tax rates are used to determine the taxes paid by the producers.

29. Equity Financing Fraction EQFR $(0 \leqslant f_E \leqslant 1)$

Def: The equity financing fraction of a facility is the fraction of capital investment which is financed with equity capital, (i.e., by selling stock or retaining corporate earnings).

Units: $ equity/$ capital investment

- -

Model Parameter: EQUITY (E)

Translation Equation:

$$E = f_E C_0, \quad \text{where}$$

C_0 is the total capital investment (specific capital cost plus interest during construction).

Then the total debt financing (D) is:

$$D = (1 - f_E)\, C_0 \,.$$

Interpretation: When new facilities are constructed, capital financing is required; this must come from debt financing or equity financing. This parameter indicates, for a particular facility, what fraction of the capital financing comes from equity.

Usage: This parameter is used in the model to determine how much of the capital cost of the plant is treated using equity financing logic and how much is treated using debt financing logic.

30. Initial Production QUAN1Y ($Q \geqslant 0$)

Def: The initial production is the initial value for the first model year output from a given process in the model. It may be changed during the iterative calculation toward the converged solution.

Units: Quads/year* (See below for the Transportation Sector)†

- -

Model Parameter: same as the above

Translation Equation: none

Usage: The initial production is the demand satisfied in the first year by the particular technology in question and is used to describe the "state" of the energy system in the initial model year in calculating initial market shares. Three values of QUAN1Y are input for electric power generation processes, where base, intermediate, and peak production quantities are needed to represent the time varying nature of the demand.

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*Or trillion Btu/year, depending upon the units in which the user wishes to specify all the quantities.

†In the Transportation Sector, each activity may have different units, depending upon the choice the user makes for the quantity demanded. In Model 22C, for example, QUAN1Y is input as trillion passenger miles, vehicle miles, and freight-ton miles per year. The important point is that the output quantity demanded must be interpreted in the same units as the input QUAN1Y.

31. Historical Capacity Additions Change Rate* RATIN ($-1 \leq r_s \leq 1$)

Def: The historical capacity additions change rate is the fractional rate or change in new nameplate capacity/year at the beginning of the model time horizon. I.e., the historical capacity additions change rate is:

$$\frac{\text{capacity additions}_t - \text{capacity additions}_{t-1}}{\text{capacity additions} \times 1 \text{ year}}$$

where t is the first year of the model horizon.

Units: 1/years

---

32. Initial Additions Flexibility† NEWFLX (NEWFLX > 0)

Def: The initial additions flexibility is the fractional increase in product price that would occur if the actual capacity addition at year (t + 1) were 10 percent greater than the committed capacity additions, i.e.,

$$\frac{\text{product price if actual capacity addition is 10\% greater than planned}}{\text{product price if actual capacity addition exactly equals level planned}}$$

Units: dimensionless

- -

Model Parameters: RATIN (same definition and units as above)

CLRATE is the committed capacity additions change rate, the yearly change in new nameplate capacity/year just after the beginning of the mode horizon.

---

*In the original DFI system, RATIN was a GLOBAL parameter used for all basic conversion and resource processes, and the model parameters defined here apply for the DFI code. In LEAP and Model 22C, RATIN is input directly for resource processes but is calculated internally for basic conversion processes and depends upon the input parameter AVEFFI (#A-6).

†NEWFLX is not used in Model 22C.

ERCHAR is the parameter of the penalty multiplier on product prices when actual new capacity is greater than planned new capacity.

Translation Equations:

CLRATE = RATIN

$$C = \frac{0.1}{\ln(1 + Z)} \quad , \qquad \text{where}$$

C = ERCHAR is the parameter of the penalty multiplier on shadow prices, and

Z = the initial additions flexibility, NEWFLX

Interpretation: Plants typically last for many years, but their operation tends to deteriorate over those years. Thus, it is necessary to specify how many plants of each age are in place at the beginning of the model horizon. Instead of specifying as input data the actual history of plant additions over, for example, the last thirty years, a simple approximation is made. This approximation is that additions to nameplate capacity increase or decrease by a constant amount each year. At the beginning of the model horizon this increase in new capacity/year is RATIN.

For many technologies, particularly capital intensive technologies having long lead times, decisions made in the years just prior to the model horizon more or less determine the capacity that will come on line in the first several years (initial year through initial year plus lead time). Instead of specifying these "initial commitments in the pipeline" as input data, we use the same simple model as described above for historical capacity additions. Just after the beginning of the model horizon, the increase in committed capacity/year is CLRATE.

An industry is not "constrained" to meet the "initial commitments in the pipeline" schedule. However, changing these previously made decisions usually involves somes cost. This is modeled by increasing the shadow price if new capacity actually added is greater than new capacity committed at the beginning

of the model horizon. The increased shadow price* reduces demand, which reduces the need for new capacity, forcing it toward the committed capacity. The multiplier on shadow prices has the form:

$$f(t) = \begin{cases} \exp\left(\dfrac{N(t) - N_c(t)}{C\ N_c(t)}\right) & N(t) > N_c(t) \\ 1 & N(t) \leqslant N_c(t) \end{cases}$$

where:

$N(t)$ is the actual new capacity at time t,

$N_c(t)$ is the committed new capacity at time t at the beginning of the model horizon, and

C is ERCHAR.

Usage: RATIN is used to calculate capacity commitments at the beginning of the model horizon in resource processes. In conversion processes, RATIN is no longer used as an input parameter. Instead, RATIN (r_s) is calculated internally and depends upon the average efficiency (E_{AV}), which has been added as an input parameter for LEAP.

*The shadow prices calculated in Model 22C are identical to the output prices.

33. Forecasting Perfection FORPER (FORPER = 1)

Only perfect foresight is presently allowed in LEAP (with FORPER = 1). That is, the producers base their decisions on a perfect forecast of future prices.

Therefore, this parameter will not receive further attention at this time.

Model Parameters: PRMS1 (called ALPHA)

Subroutines: FRCST, FRCSTM, and INVFRC are bypassed.

34. Historical Inflation Rate RINF1 ($I_f' < 1$)

Def: The Historical Inflation Rate is the average rate of inflation before the first model time period.

Units: percent/year (10% per year would be input as 0.1)

---

35. Terminal Inflation Rate RINF2 ($I_f < 1$)

Def: The Terminal Inflation Rate is the average rate of inflation after the last model time period.

Units: percent/year (10% per year would be input as 0.1)

- -

Model Parameters: same as the above

Translation Equation: none

Usage: RINF is used to inflate or deflate cash flows after or before the model time horizon.

36. Capacity Factor Cost Multiplier CFMULT ($\alpha > 0$)

Def: The capacity factor cost multiplier is the ratio of the output price to the variable operating cost at which the capacity factor is equal to one half its maximum value.

Units: dimensionless

---

37. Capacity Factor Price Sensitivity CFSENS (CFSENS > 0)

Def: The capacity factor price sensitivity is the ratio of the output price to the variable operating cost at which the capacity factor is equal to 90% of its maximum value. That is, CFSENS = P/ϕ when the capacity factor is 0.9 β. Thus, CFSENS determines the value of γ, which is derived below.

Units: dimensionless

- -

Model Parameters: OPALP = CFMULT = α ; OPGAM = γ ; OPBET = β .

The maximum value of the capacity factor is obtained when: $C_f = \beta$. Note that β = AVAIL × LOADFC and,

$$C_f = \frac{\beta}{1 + (\alpha\phi/P)^{\gamma}} \quad , \quad \text{then } (\alpha/\text{CFSENS})^{\gamma} = \frac{1}{9} \text{ , and}$$

$$\gamma = (\ell n\ 9)/[\ell n\ (\text{CFSENS}/\alpha)] \ .$$

Note: Unfortunately, however, γ is incorrectly coded in LEAP and the DFI demonstration model* where it is given as:

$$\gamma = (2\ \ell n\ 9)/(\ell n\ W), \quad \text{where } W = \text{CFSENS and } \alpha = 1.$$

---

*According to Steve Haas, the DFI model is being corrected, p.c., 1980. The authors are grateful to him for his comments and suggestions.

α = CFMULT

ϕ = the variable operating cost per unit of energy (including fuel)

P = output price per unit of energy

Usage: The capacity factor function occurs in the up-pass pricing calculation and in the down-pass determination of input quantities.

38. Assessed Value Inflator INFLAT ($I \geq 1$)

Def: Assessed value inflator is a multiplier on the assessed value of a facility. It affects the property taxes which will be paid to local government.

Units: dimensionless

- -

Model Parameter: same as above

Translation Equation: none

Interpretation: The assessed value of a plant for property tax purposes in year t is equal to:

$$m(t) = \frac{INFLAT(t)}{INFLAT(t_0)} \times SCC(t_0) ,$$

where SCC is the Specific Capital Cost (Parameter #5)

and t_0 is the initial year of operation.

Usage: Since m(t) determines the value of the property, then the property tax in year t is:

$$PTRATE \times m(t) ,$$

where PTRATE is the property tax rate (Parameter #28).

39. Fraction of Energy ENFRC $[0 \leq fr_i \leq 1]$

$$\sum_i fr_i = 1$$

Def: The ith fraction of energy is the quantity of energy demanded at load factor i divided by the total quantity of energy demanded.

Units: dimensionless

- -

Model Parameter: same as the above

Translation Equation: none

Interpretation: The fraction of energy generated at load factor i is taken from the discrete approximation to the load duration curve. It represents the fraction of total annual electricity demand that occurs at (or near) load factor i. The three load factors are: Base, Intermediate, and Peak.

Usage: ENFRC is used to determine the average price, p, of electricity (on the up pass).

$$p = \sum_i p_i \, fr_i \quad , \qquad \text{where}$$

p_i is the price of electricity at load factor i.

The price is then used in the down pass to determine the demand for electricity at load factor i given the total demand for electricity, i.e.,

$$q_i = q \, fr_i \quad , \qquad \text{where}$$

q is the total electricity demand and q_i is the demand for energy at load factor i.

40. Initial Resource Cost INRCST ($I_{NR} > 0$)

Def: The initial resource cost is the minimum levelized price path needed to add a unit of resources to reserves at the beginning of the model horizon (or at the year of availability, if that is after the beginning of the horizon). I.e., suppose one were going to build a new resource facility (well or mine) at the most attractive undeveloped, uncommitted resource deposit available. What levelized price path would be required to build and operate it without incurring a loss, where costs include normal return to capital, but exclude any resource rents.

Units: $/MMBtu

- -

Model Parameters: C1, C2, O1, O2, OIO, CIO

Translation Equations: Given in the section following Def. #48.

Interpretation: The definition above is complete. In specifying INRCST, it is important to understand that the following are distinct questions which, in general, have different answers:

1. What is the minimum levelized price leading to a non-negative present value of cash flow for a unit resource facility committed at t_0, the beginning of the model horizon, where a "unit" facility is one whose maximum cumulative production over its lifetime is one unit?

2. What is the minimum lump sum cash payment which the owners of that facility would accept at t_0 in exchange for the right to all revenues generated by it?

The data parameter INRCST is the answer to the first question. In general, it is higher than the answer to the second question. The answer to the second question is the present value of total cost of

building the resource facility at t_0 and operating it over its lifetime. Denote this as TC_0. Then

$$TC_0 = c_0 + \int_{t_0}^{\infty} \phi(t_0,t)\ q(t)\ e^{-\int_{t_0}^{t} r(\tau)d\tau}\ dt$$

where c_0 = capital cost of the facility built at t_0

$\phi(t_0,t)$ = operating cost per unit of production at time t from a plant built at t_0.

$q(t)$ = production rate at t when $\left(\int_{t_0}^{\infty} q(t) \leqslant 1\right)$

$r(t)$ = producer's interest rate at t.

To operate the facility at the breakeven point, the present value of revenue generated by the levelized price path from question (1) above must equal TC_0. Let TR_0 denote this revenue and $\bar{p}$ the levelized price. Then,

$$TR_0 = \int_{t_0}^{\infty} \bar{p}\ q(t)\ e^{-\int_{t_0}^{t} r(\tau)d\tau}\ dt$$

If the unit facility is operated at capacity over its lifetime, we have

$$q(t) = \delta e^{-\delta(t-t_0)}$$

where δ = deposit decline rate (Parameter #47).

Further, if the interest rate is constant at r, we have

$$TR_0 = \left(\frac{\delta}{r+\delta}\right)\bar{p}\ .$$

Thus the answer to question (1) is $\bar{p}$ (which is data parameter INRCST), while the answer to question (2) is TC_0.

Usage: This data parameter is used in conjunction with several other parameters to calibrate two resource cost curves, each of which defines a cost multiplier as a function of cumulative new resource commitments to date. One curve is for the capital cost components of a new resource-producing facility, and one is for its initial operating cost. See the section following Definition 48 for the details of how the data parameters are translated to the model parameters.

41. Base Resource Price BASEPR (BASEPR > INRCST)

Def: The base resource price is a levelized price selected by the user such that specifying the resources available at this price (in the sense of data definition 40) and at twice this price (definitions 42 and 43) determines the relevant part of the resource curve.

Units: $/MMBtu*

- - - - - - - - - - - - - - - - - - -

Model Parameters: See Def. #40.

Translation Equation: Given in the section following Def. #48.

- -

*Or trillion Btu, depending on the units in which the user wishes to express all quantities.

42. Undiscovered Recoverable Resources UNRCRS (UNRCRS > 0)

Def: Undiscovered recoverable resources is the amount of resources in addition to reserves (where reserves equal unproduced commitments) at the beginning of the model horizon that could be developed and produced under a levelized real price equal to the base resource price (Definition 41) such that the present value of their associated cash flows are non-negative (where the opportunity costs of capital are to be included but all resource rents are excluded). The discount rate to be used in the cash flow calculations is equal to the return on equity in the first period of the model horizon. UNRCRS should include any expected future resource discoveries that meet this test.

Units: Quadrillion Btu*

- -

Model Parameters: See Def. #40.

Translation Equation: Given in the section following Def. #48

---

*Or trillion Btu, depending on the units in which the user wishes to express all quantities.

43. New Resources at Doubled Base Price NEWRS2 (NEWRS2 > UNRCRS)

Def: New resources at doubled base price is the amount of new resources in addition to reserves at the beginning of the model horizon, including expected new discoveries, that could be produced without a loss, in the sense of Definition #42 at a levelized real price equal to twice the base resource price of Definition #41.

Units: Quadrillion Btu *

- -

Model Parameters: See Def. #40

Translation Equation: Given in the section following Def. #48.

---

*Or trillion Btu, depending on the units in which the user wishes to express all quantities.

44. Current Capital Cost Fraction CCCF ($0 \leqslant C_c \leqslant 1$)

Def: The capital cost fraction is the fraction of the present value of the cost of building a resource facility and operating it over its entire lifetime that is allocated to capital factors. The current CCF is the capital cost share of a facility built today.

Units: dimensionless

---

45. Undiscovered Capital Cost Fraction* UCCF ($0 \leqslant UCCF \leqslant 1$)

Def: The undiscovered capital cost fraction is the capital cost share when cumulative new resource commitments reach the level of undiscovered recoverable resources (Parameter #42).

Units: dimensionless

---

46. New Resources Capital Cost Fraction* NCCF ($0 \leqslant NCCF \leqslant 1$)

Def: The new resources capital cost fraction is the capital factor share when commitments have reached the level of new resources at doubled prices (Parameter #41).

Units: dimensionless

- - - - - - - - - - - - - - - - -

Model Parameters: See Def. #40.

Translations Equations: Given in the section following Def. #48.

---

*Neither of these parameters are implemented in the present version of LEAP and therefore could not be used in Model 22C.

Interpretation: The present value of total cost may be divided into capital cost and operating cost. These parameters are just the fraction of the total that is capital cost, at various levels of resource commitment. In the present version all of these parameters are equal.

47. Deposit Decline Rate DCLNO ($\delta > 0$)

Def: The deposit decline rate is the rate at which the maximum physical output capacity of a unit resource producing facility would decline if the facility were run at full capacity. It translates roughly to the inverse of the reserves-to-production ratio.

Units: Percent/year (10% should be entered as 0.10)

- - - - - - - - - - - - - - - - - -

Model Parameter: same as above

Translation Equations: none

Interpretation: Define a unit resource production facility as a facility which can technically produce one unit of resource over its lifetime. Let,

$Q(t)$ = cumulative production from the unit facility at time t,

$R(t) = [1 - Q(t)]$ = facility's reserves remaining at time t (a unit facility by definition can ultimately produce one unit of resource), and,

$\bar{q}(t)$ = maximum production rate at t from the facility.

Then, it is assumed that:

$\bar{q}(t) = \delta R(t)$, where

δ = deposit decline rate.

It can be seen that $1/\delta = R(t)/\bar{q}(t)$, the remaining reserves to maximum production ratio.

Usage: The deposit decline rate is used in Subroutine ROCD to calculate DCLN(t), the maximum production rate at time t from a given facility, which is the same as $\bar{q}$ above.

48. Owner Interest Rate ROWN ($r_0 > 0$)

Def: The owner interest rate is the rate used by the original owner of a resource deposit to discount cash flows resulting from the sale of leases to resource producers. It is assumed to be constant over time.

Units: percent/year (5% per year would be input as 0.05)

- - - - - - - - - - - - - - - - -

Model Parameter: same as the above

Translation Equation: none

Usage: ROWN is used in the pricing subroutine, RPRICE.

TRANSLATION OF DATA PARAMETERS TO MODEL PARAMETERS FOR RESOURCE COST CURVES

This discussion shows how the model parameters, C_{c1}, C_{c2}, O_{c1}, O_{c2}, CIO, and OIO, are determined from the resource-specific data parameters and describes their usage. Denote these parameters as follows:

I_{NR}	=	initial resource cost (Def. # 40)
BASEPR	=	base resource price (Def. # 41)
UNRCRS	=	undiscovered recoverable resources (Def. # 42)
NEWRS2	=	new resources at doubled prices (Def. # 43)
C_c	=	current capital cost fraction (Def. # 44)
UCCF*	=	undiscovered capital cost fraction (Def. # 45)
NCCF*	=	new resources capital cost fraction (Def. # 46)
C_{LF}	=	capital labor fraction (Def. # 6)
f_1	=	operating labor fraction (Def. # 8)
V_o	=	variable operating cost, excluding fuel.†

The model parameters are determined from these input data parameters as follows:

Translation Equations:

$$(1)\quad C_{c2} = \frac{\ln\left(\dfrac{2 \times NCCF \times BASEPR - C_c \times I_{NR}}{UCCF \times BASEPR - C_c \times I_{NR}}\right)}{\ln\left(\dfrac{NEWRS2}{UNRCRS}\right)}$$

$$(2)\quad C_{c1} = \left(\frac{UCCF \times BASEPR - C_c \times I_{NR}}{C_c \times I_{NR}}\right) UNRCRS^{-C_{c2}}$$

---

*In LEAP, UCCF = NCCF = C_c .

†In LEAP, $V_o = (1 - C_c) \times I_{NR}$.

$$(3)\quad O_{c2} = \frac{\ln\left(\dfrac{2(1 - NCCF)BASEPR - (1 - C_c)I_{NR}}{(1 - UCCF)BASEPR - (1 - C_c)I_{NR}}\right)}{\ln\left(\dfrac{NEWRS2}{UNRCRS}\right)}$$

$$(4)\quad O_{c1} = \left(\frac{(1 - UCCF)BASEPR - (1 - C_c)I_{NR}}{(1 - C_c)I_{NR}}\right) UNRCRS^{-O_{c2}}$$

$$(5)\quad CIO(1) = C_{LF} \times S_c$$

$$CIO(2) = (1 - C_{LF}) \times S_c$$

$$OIO(1) = f_1 \times V_o$$

$$OIO(2) = (1 - f_1) \times V_o$$

The derivations of Equations (1) through (5) are given in Ref. 1. In LEAP, S_c is calculated as follows:

$S_c = (C_c \times I_{NR})/(\alpha_1 \times N_{CO})$, where,

α_1 = the intra-period discount factor, and

N_{CO} = the present value (depletion free) of the capital cost.

49. Half-Depletion Cost Multiplier HDCMLT (HDCMLT $\geqslant$ 1)

Def: The half-depletion cost multiplier is the operating cost increase factor when half of the facility's ultimately available resources have been depleted.

Units: dimensionless

---

50. Full-Depletion Cost Multiplier (FDCMLT $\geqslant$ HDCMLT)

Def: The full-depletion cost multiplier is the operating cost increase factor when all of the facility's ultimately available resources have been depleted.

Units: dimensionless

- - - - - - - - - - - - - - - - - - -

Model Parameters: V1 and V2 are the parameters used to fit the function which gives the factor, ROPROM, by which the operating cost is increased at a given resource production facility as a function of cumulative production from that facility.

Translation Equations:

$$V1 = B(1.0) - 1$$

$$V2 = \frac{\ln [B(0.5) - 1] - \ln [B(1.0) - 1]}{\ln (0.5)}$$

where,

B(0.5) = Half-Depletion Cost Multiplier = $1 + V1(0.5)^{V2}$

B(1.0) = Full-Depletion Cost Multiplier = $1 + V1(1.0)^{V2} = 1 + V1$

Interpretation: These parameters are facility specific multipliers which measure the factor by which operating cost is increased at a given facility compared to the operating cost at the facility's opening date.

Usage: These data parameters are used, via the translation equations above, to calibrate the cost multiplier function, ROPROM, defined under "Model Parameters." This function is the following:

$$ROPROM = 1 + V1 \times Q^{V2}, \text{ where}$$

Q = cumulative resource production to date from a given unit facility, with

$$0 \leqslant Q \leqslant 1.$$

Note: Nomenclature used in Ref. 1:

$V1 = C_1$

$V2 = C_2$

51. Regulatory Policy REGTST (REGTST $\varepsilon\{0,1\}$)

Def: Regulatory policy is a logical variable which is set to 1 if the resource prices are regulated and to 0 if they are not.

Units: dimensionless (logical)

---

52. Price Ceiling REGPR (REGPR > 0)

Def: Price ceiling is a time vector which gives the period-by-period schedule of regulated price ceilings.

Units: $/MMBtu

- - - - - - - - - - - - - - - - - -

Model Parameters: same as the above

Translation Equation: none

Usage: If REGTST is 1, the program calls a subroutine (REGLAT) which computes a vector of shadow prices which, through the model logic, insures that all three of the following are true in the final equilibrium solution:

(1) The regulated price ceilings are not violated.

(2) The resource output schedules are consistent with the resource suppliers' behavioral model, given the regulated prices.

(3) The consumers buy only the resources supplied, even though demand may be greater.

Note: Neither REGTST nor REGPR are used in Model 22C.

53. Terminal Resource Multiplier TRMULT (TRMULT $\geqslant$ 1)

Def: The terminal resource multiplier is defined as:

$$\frac{\text{estimated product price at end of model horizon*}}{\text{marginal cost of product at year of availability}} \times \text{technological change multiplier}$$

Units: dimensionless

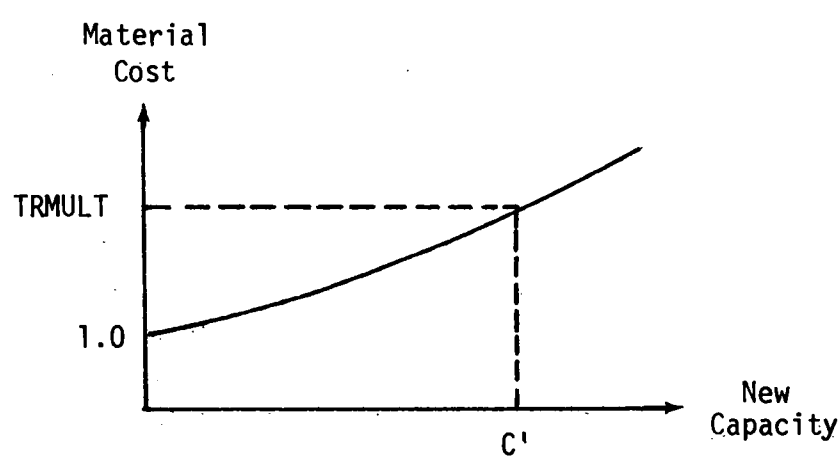
- - - - - - - - - - - - - - - - - -

Model Parameter: same as the above

Translation Equation: none

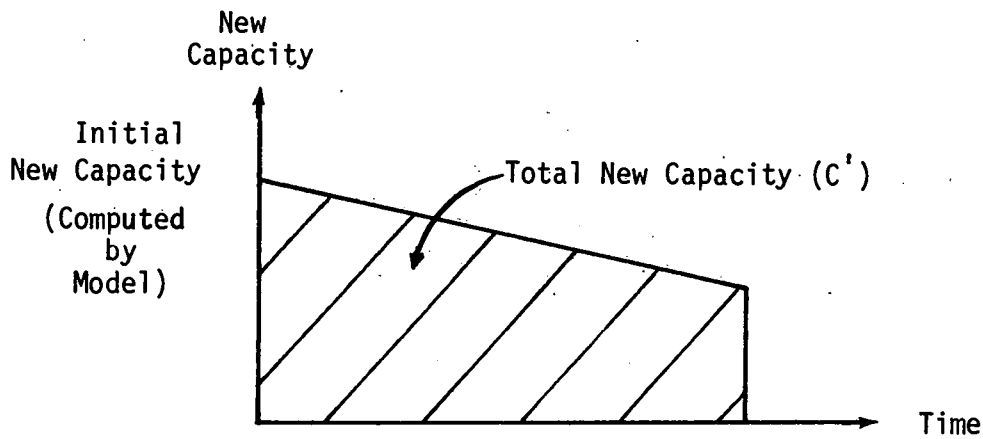
Usage: This parameter is used when cold-starting the model to derive an estimate of capacity additions over time (Subroutine NEWSRT).

This parameter is also used during the calculation of the resource commitment multipliers on operation and maintenance cost (RCMTOM) and on capital cost (RCMTCC). If RCMTOM or RCMTCC is greater than 2 x TRMULT, then the final value is set equal to 2 x TRMULT.



*Or the beginning of the model horizon if the technology is already available.

If TRMULT is estimated as in the figure, then total new capacity over the model horizon is estimated at C'. This capacity is assumed to be added according to the following diagram:



54. Distance DIST (D > 0)

Def: This is the distance over which a material is carried by a transportation process.

Units: Reference distance units (e.g., thousands of miles)

- - - - - - - - - - - - - - - -

Model Parameter: same as the above

Translation Equation: none

Interpretation: Specific capital cost, variable operating cost, and efficiency of transportation processes are stored in the data base for a reference distance (e.g., 1000 miles). These must be adjusted to correspond to the actual distance covered by a transportation process.

Usage: In the interface to the transportation process the following adjustments occur:

$$SCC' = SCC \frac{D}{REFDIST},$$

$$VOC' = VOC \frac{D}{REFDIST}, \text{ and}$$

$$EFF' = (EFF)^{D/REFDIST},$$

where SCC, VOC, and EFF are the specific capital cost, variable operating cost, and efficiency for a transportation process whose length is the reference distance, REFDIST, and the primed variables are the same parameters for a transportation process whose length is D.

Note: This parameter was not used in Model 22C.

55. Input-Output Coefficient ROIO (ROIO > 0)

Def: The input-output coeffieient is the usable energy per unit of output for an end-use consumption process with multiple fuel inputs.

Units: Energy/Person or Energy/Unit of Industrial Activity or Energy Input/Energy Output

- - - - - - - - - - - - - - - - -

Model Parameter: OIO(j) is the operating input-output coefficient for th j^{th} input to a process.

Translation Equation:

$$ROIO(j) = OIO(j)$$

Interpretation: Final demand for the ith type of usable energy in the Demonstration Model is equal to a specified output (population for the consumer process and GNP for the industrial process) times the corresponding input-output coefficient.*

For a conversion process with multiple fuel inputs, the demand for each fuel input is equal to the output times the corresponding input-output coefficient.

Usage: Each input-output coefficient is multiplied by a learning multiplier identical in form to the technological change multiplier used in the conversion process. Thus:

*In LEAP, the demand is determined by the demand elasticities (See Appendix C).

$$
\begin{aligned}
OIO(j,t) &= OIO(j)[L+(1-L)(1-\gamma_\ell)^{t-t_A}], && t \geqslant t_A \geqslant t_G(1) \\
&= OIO(j)[L+(1-L)(1-\gamma_\ell)^{t-t_G(1)}], && t \geqslant t_G(1) \geqslant t_A \\
&= OIO(j)[1+(t_A-t)\rho], && \begin{cases} t_A \geqslant t_G(1) \\ t_A \geqslant t \end{cases} \\
&= OIO(j)\left\{1+\left[\frac{2T_{EF}-2E_{AV}}{0.8T_{EF}L_c}\right][t-t_G(1)]\right\}, && t_G(1) \geqslant t \geqslant t_A \\
&= OIO(j)\left\{1+\left[\frac{2T_{EF}-2E_{AV}}{0.8T_{EF}L_c}\right][t_A-t_G(1)]\right. \\
&\qquad \left. + [t_A-t]\rho\right\}, && t_G(1) \geqslant t_A \geqslant t
\end{aligned}
$$

where

$OIO(j,t)$ = the jth coefficient in year t,

L = PROLIM (Def. #17),

γ_ℓ = VOCRAT (Def. #18),

t = year facility is built

t_A = year of commercial availability,

$t_G(1)$ = first model year,

ρ = pre-commercial premium/year,

T_{EF} = thermal efficiency (Def. #9),

E_{AV} = average efficiency (Def. #A-6), and

L_c = characteristic facility life (Def. #22).

APPENDIX B

GLOBAL PARAMETERS AND THOSE NOT IMPLEMENTED IN LEAP MODEL 22C

Several parameters are defined by DFI[3] and/or the EIA,[2,5] but do not seem to be implemented in the subroutines for the 1978 LEAP-EMS and/or in the choices made for Model 22C. That is, the subroutine may exist in LEAP, but the choice of the Model 22C parameter performs only one task, that of bypassing that subroutine.

The parameters which have the same value for all (or almost all) of the activities in Model 22C have been labeled "GLOBAL" by LTEAD, therefore these are tabulated separately and the source given only once, which avoids lengthy duplication. The LTEAD method has been carried over here and combined with the same treatment for those parameters which are not implemented, since, in one sense they are considered GLOBAL in nature.

GLOBAL parameters may be time dependent in that a value is required for each model time point (five-year increments from 1975 to 2020); the behavioral parameters, SENS and ELAS, are not used until the year 2000. Although time dependence is allowed for parameters A-7 through A-10, they were chosen as constants for Model 22C. These parameters are tabulated along with the information provided regarding the source upon which the numerical values were based. The symbolic nomenclature used to identify the "source" is specified in the references at the end of these Appendices.

TIME-DEPENDENT "GLOBAL" PARAMETERS (MODEL 22C)

Parameter No.

none POPULATION GROWTH RATE (Neither data nor source given)

Assumptions about birth rates and immigration rates are not provided, but a comment is included which implies that the population growth rate will decrease to about 0.5%; the beginning year is not given. Presumably, this information is folded into the demand elasticities.

A-3 GROSS NATIONAL PRODUCT (GNP) GROWTH RATE (Units: percent/year)

1975-1995	0.0	4.6	3.5	3.0	2.9

Source: MEFS[10] Input Data (Read as average of previous five-year bin)

1995-2020 Constant at 2.4

Source: Average taken from the Hudson-Jorgenson model for NEP-2.[11]

ALTHOUGH THE FOLLOWING PARAMETERS ARE ALLOWED AS INPUT FOR EACH MODEL YEAR, THEY HAVE BEEN CHOSEN AS CONSTANT IN MODEL 22C

Parameter No.	FORTRAN Name	Parameter Name	Source	Value
A-7	ROE(t)	Return on Equity	LTEAD[6]	(0.1)[a]
A-8	RDEBT(t)	Return on Debt	LTEAD[6]	(0.04)
A-9	PLI(t)	Price of Labor	LTEAD[6]	(1.0) (null value)
A-10	PMI(t)	Price of Materials	LTEAD[6]	(1.0) (null value)

[a] "Set by the Long-Range Division to approximately a 7% after tax return with no inflation when combined with RDEBT."

TIME-INDEPENDENT "GLOBAL" PARAMETERS (MODEL 22C)

Parameter No.	FORTRAN Name	Parameter Name	Source	Value
A-1	SENS[a]	Behavioral Lag (Demand)	LTEAD & CSRRD (EIA)[6,7]	(0.8)
A-2	ELAS[a]	Price Elasticity	LTEAD & CSRRD (EIA)[6,7]	(-0.1)
A-11	NPOINT	Number of Points	Model Definition[3] (DFI)	(10.0)
A-12	DEL	Length of Time Periods	Model Definition[3] (DFI)	(5.0)
A-13	NSHORT	Number of Short Periods/Long Period	Model Definition[3] (DFI)	(1.0)
4	PRIC1Y	Initial Product Price	Not given (Place-holder, only)	(10.0)[b]
6	CLFR[c]	Capital Labor Fraction	National Coal Model Data - Coal, Shale, & Uranium	(0.37)
			Long-Term Div. Assump. - Oil and Gas	(0.0)
			EPRI[8] (all others)	(0.4)

[a]These parameters apply only for the time period from the year 2000 to 2020. According to LTEAD, ELAS was chosen so that, "The resulting long-run elasticity divided by one minus the behavioral lag is -0.5, with a 50 percent response in 4 years." The choice made for these parameters, however, gave a 50 percent response in 20 years, not four years. See a discussion on this problem in Section VI.

[b]Except for electric power generation processes, where PRIC1Y may have different input values for base, intermediate, and peak loads.

[c]Since PLI and PMI are set equal to 1.0 in Model 22C, this parameter is not used.

TIME-INDEPENDENT "GLOBAL" PARAMETERS (MODEL 22C) (cont'd.)

Parameter No.	FORTRAN Name	Parameter Name	Source	Value
8	OLFR	Operating Labor Fraction	EPRI [8]	(0.4)[d]
11	CFLDR	Capital Factor Lead Ratio	EPRI[8] (after modification by LTEAD due to change in definition, which was not provided)	(0.167)
			Coal and Other Resources	(0.170)
13	EARLY	Pre-Commercial Premium/Year	LTEAD[6]	(0.1)
17[e]	POSTLM	Production Time-Based Operating Technological Change Limit	LTEAD[6]	(1.0) (null value)
20	AVAIL	Availability	EPRI[8]	(0.9) (except utilities)
21	LOADFC	Load Factor	DFI[3] (Model Definition)	(1.0) (null value, except utilties)
23	VOAGRT[f]	Facility Aging Rate	DFI[3] (Model Definition)	(3.0)
26	INCTAX	Income Tax Rate	EPRI[8] (Modified)	(0.25 Residential) (0.52 All Others)

[d]The value of 0.61 has been used for coal production only.

[e]This parameter is not listed as a GLOBAL parameter by LTEAD.

[f]Due to the fact that VOAGRT was input as 3.0 in Model 22C instead of 3%, an override was built into LEAP to *reset* the model parameter if calculated to be greater than 20. Since the calculated model parameter was always greater than 20, the Model 22C output projections do not depend upon the value of this input parameter.

TIME-DEPENDENT "GLOBAL" PARAMETERS (MODEL 22C) (Cont'd)

Parameter No.	FORTRAN Name	Parameter Name	Source	Value
27	ITCRAT	Investment Tax Credit Rate	EPRI[8]	(0.1)
28	PTRATE	Property Rax Rate	EPRI[8]	(0.0 Residential) (0.02 All Others)
32	NEWFLX[g]	Initial Additions Flexibility	None	(0.98%)
33	FORPER	Forecasting Perfection	LTEAD[6]	(1.0) (Perfect Foresight) null value
34	RINF1	Historical Inflation Rate	LTEAD[6]	(0.0) null value
35	RINF2	Terminal Inflation Rate	LTEAD[6]	(0.0) null value
36	CFMULT	Capacity Factor Cost Multiplier	DFI[3] (Model Definition)	(1.0) null value
37	CFSENS	Capacity Factor Price Sensitivity	DFI[3] (Model Definition)	(1.34)[h]
38	INFLAT	Assessed Value Inflator	LTEAD[6]	(1.0) null value
48	ROWN[i]	Owner Interest Rate	LTEAD[6]	(7.98%)

[g]This parameter is not listed as GLOBAL by LTEAD although the same value is specified for conversion, end-use conversion, electric-power conversion, resources (oil, gas and coal), transportation and distribution processes. NEWFLX, however, is *not* used in Model 22C.

[h]If this parameter has a value less than 1.2, it will be overridden by LEAP which allows a minimum value of 1.2.

[i]Although these parameters do not appear in the EIA GLOBAL list for Model 22C, they always have the same input values.

TIME-INDEPENDENT "GLOBAL" PARAMETERS (MODEL 22C) (cont'd.)

Parameter No.	FORTRAN Name	Parameter Name	Source	Value
49	HDCMLT[i]	Half Depletion Cost Multiplier	LTEAD[6]	(1.0) null value
50	FDCMLT[i]	Full Depletion Cost Multiplier	LTEAD[6]	(1.0) null value
51	REGTST	Regulatory Policy	DFI[3] (Model Definition)	(0.0) null value
52	REGPR[j]	Price Ceiling	None	not specified
54	DIST[k]	Distance	LTEAD[6]	(1.0) null value
	ADDITIONAL PARAMETERS NOT PROGRAMMED IN LEAP			
45	UCCF	Undiscovered Capital Cost Fraction		
46	NCCF	New Resources Capital Cost Fraction		

[i]Although these parameters do not appear in the EIA GLOBAL list for Model 22C, they always have the same input values.

[j]Although this parameter does not appear in the EIA GLOBAL list of parameters, it is a constant for all sectors where it appears.

[k]Although this parameter is occasionally input, for example, in Activities 7.11 (Transport Alaskan Oil) and 7.13 (Transport Alaskan Gas), the choice of 1.0 as input does not modify the output. No input values were found for Activities 6.7, 6.8, 6.9, and 6.27.

APPENDIX C

ALLOCATION, BASIC CONVERSION AND RESOURCE PARAMETERS FOR THE ACTIVITIES USED IN MODEL 22C

This Appendix contains the tabulated values of the input parameters involved in each activity of the ten sectors of Model 22C. The various activities for each sector are categorized and tabulated separately upon the generic process basis (i.e., allocation, conversion, resource, etc.). Each activity table includes the FORTRAN name, list of the parameters, the value of each parameter, the source of this value and the units in which it is expressed.

Several of the 150 nodes in Model 22C are "null" in that the input data provided, no matter how extensive, do not operate on the input/output prices or quantities on the up- and down-pass. The data tables for most of these nodes have therefore been deleted for the sake of brevity. It should be noted that PRICIY (Parameter #4) is not tabulated since it appears as an input condition which is changed in the iterative process.

The ten sectors for Model 22C follow the network diagram described by Figs. A-1 through A-9 of Ref. 4. Residential, Commercial, Industrial and Transportation Sectors represent the Demand for energy provided through the Distribution Sector from the Utilities Sector for electrical services and ultimately, from the resource supply sectors, Uranium, Oil/Gas, Coal and Synthetics and Imports/Exports.

APPENDIX C.1

MODEL 22C DATA BASE FOR THE RESIDENTIAL SECTOR

The Residential Sector (as diagramed in Fig. A-1 of Ref. 4) contains three allocation activities representing:

a) combined space and water heat (from oil, gas, electric, and solar activities),

b) space cooling, cooking and other (from "cooking and other electric" and "cooking and other gas" activities), and

c) electrical services (from electric and distributed photovoltaic and wind activities).

A residential demand activity represents the demand for services as a function of population and GNP. The demand elasticities are derived from the Structural Residential Energy Demand (Hirst) model[12] for the first five periods and extrapolated linearly to equal the ratio of population growth* to GNP growth by 2020. Most of the capital and operating costs and some efficiency data were taken directly or derived from Brookhaven data.[9] The remainder of the efficiency values were derived from the Hirst model.[12] Equal price shares and initial quantities were generated by the Long-Term Division from MEFS[10] and Hirst[12] model data. Other less significant values came from DFI[3] and the Long-Term Division.[6]

Table C.1.a contains the values of the allocation parameters and Table C.1.b the basic conversion parameters for the residential sector. The demand elasticities are tabulated in Table C.1.c and illustrated in Fig. C.1.

---

*The population growth rate assumed by the modelers is not given, as discussed in Appendix B.

Table C.1.a. Residential Sector: Allocation Parameters for Model 22C

Activity	Description	SHSENS (dimension-less)	BELAG (years)	FREQPR (Shares at Equal Prices) in Percent				
				Oil	Gas	Electricity	Solar	Photo-Voltaics & Wind
1.1	Space and Water Heat[a]	5.0	9.0	36.5	9.0	53.5	1.0	
1.12	Cooking and Appliances (except Refrigerators and Freezers)	2.5	3.0		2.5	97.5		
1.15	Lighting, Refrigerators, and Freezers[b]	5.0	9.0			90.0		10.0

[a]Source and comments: LTEAD[6]

"Penetration of solar heat is not adequately accounted for due to lack of data."

"1975 shares are derived from the Hirst model[12] of residential fuel use. Equal price shares and behavioral lag are adjusted to calibrate 1995 forecasted shares against the Hirst 1995 forecast."

[b]Condensed from comments by LTEAD: No data available for distributed electricity production. Shares at equal prices allow only negligible penetration due to siting, storage, and other limitations.

Table C.1.b. Residential Sector: Basic Conversion Parameters for Model 22C

#	Parameter	Oil (+ LNG) Heater Act. 1.3	Gas Heater Act. 1.4	Solar Heater[a] Act. 1.5	Electric Heater Act. 1.6	Lighting, Freezers, Refrig. Act. 1.7	Cooking & Other Electric Act. 1.8	Cooking & Other Gas Act. 1.9	Space Cooling Electric Act. 1.13	Photo-Voltaics, Wind, etc. Act. 1.14	Units
5	SCC	51.02[b]	38.35[b]	149.0[b]	36.72[b]	0.0[c]	18.02[d]	20.27[d]	46.49[b]	208.0[e]	$/MMBtu/yr
7	VOC	0.88[b]	0.68[b]	1.18[b]	0.59[b]	0.0[c]	0.0[f]	0.0[f]	0.40[b]	0.7400[b]	$/MMBtu
9	EFF	0.632[g]	0.60[g]	4.0[h]	0.956[g]	0.30[g]	1.0[f]	0.694[f]	2.11[i]	1.0000[j]	dimensionless
A-6	AVEFFI	0.632[k]	0.60[k]	1.0[j]	0.956[k]	0.30[k]	1.0[k]	0.694[k]	2.11[k]	1.0000[j]	dimensionless
19	EFLIM	1.29[k]	1.38[k]	1.100[i]	2.5[ℓ]	1.18[k]	1.17[k]	1.34[k]	1.4[k]	1.0000[j]	dimensionless
18	VOCRAT	0.07[k]	0.08[i]	0.0099[i]	0.05[k]	0.17[i]	0.17[k]	0.20[k]	0.09[k]	0.0098[m]	per year
30	QUANTY	1.94[n]	3.01[n]	0.0[n]	0.69[n]	0.20[o]	0.45[o]	0.49[o]	0.68[n]	0.0[p]	quads/yr
10	IPLTIM	3[c]	3[c]	5[i]	3[c]	3[c]	3[i]	2[i]	2[i]	5[i]	years
12	IYRAVL	1930[c]	1930[c]	1975[i]	1930[c]	1930[c]	1930[i]	1930[i]	1965[i]	1985[i]	year
14	CLIM	1.0[c]	1.0[c]	1.0[i]	1.0[f]	1.0[i]	1.0[f]	1.0[f]	1.0[c]	1.0[i]	dimensionless
15	CRATE	0.098[q]	0.098[r]	0.0498[m]	0.0[f]	0.0[m]	0.098[m]	0.0[m]	0.0[c]	0.0498[m]	per year
16	PRELIM	1.0[i]	1.0[i]	1.0[i]	1.0[i]	1.0[i]	1.0[i]	1.0[i]	1.0[i]	1.0[i]	dimensionless
22	ICLIFE	15[i]	15[i]	15[i]	15[i]	14[i]	10[i]	10[i]	10[i]	25[i]	years
24	ITXLIF	0[f]	0[f]	0[f]	0[f]	0[i]	0[f]	0[f]	0[f]	20[i]	years
25	IDLIFE	5[i]	5[i]	5[i]	5[i]	1[i]	1[i]	1[i]	5[i]	25[i]	years
29	EQFR	0.0998[i]	0.0998[i]	0.0998[i]	0.0998[i]	1.0[c]	1.0[f]	1.0[f]	0.0998[i]	0.6000[i]	$Equity/$Capital

FOOTNOTES

[a]This node (Solar Space Heat) was stated to have been removed from the system since penetration was negligible using these input parameters. The initial conditions still appear in the data base, however, and output projections are calculated in the code.

[b]Derived from BNL data. LTEAD comments: for oil, "... costs are BNL values for distillate heating, assuming a low load factor. Further adjustments are made to account for differences in aggregate approaches."

[c]DFI. LTEAD comments: "... conglomerate of several appliances, cost data difficult to calculate."

[d]BNL (miscellaneous resistance heat).

[e]"Not properly represented."

[f]BNL.

[g]LTEAD, assumed same as average efficiency.

[h]BNL, western electric backup.

[i]LTEAD.

[j]"Not applicable."

[k]LTEAD, derived from Hirst model.

[ℓ]LTEAD, derived from BNL. LTEAD comments: "The efficiency limit is BNL efficiency for electric heat pumps, raised to account for solar penetration. In effect, this activity combines with 1.5 for solar heat."

[m]"Not used."

[n]LTEAD, using 1975 energy balance (EIA).

[o]LTEAD, using 1975 energy balance and Hirst model for shares.

[p]LTEAD, "Not commercially available in 1975."

[q]DFI (not used).

[r]BNL (not used).

Table C.1.c. Residential Sector; Demand Elasticities for Model 22C (dimensionless)

Node	Activity	Model Year 1975	1980	1985	1990	1995	2000	2020
1.	Space and Water Heat	0.9870	0.4997	0.1720	0.5193	0.2498	0.1138	0.1827
2.	Space Cooling (Electric only)	1.086	1.875	1.517	1.786	1.389	1.212	0.1827
3.	Cooking and Other Appliances	1.015	1.061	0.6244	0.7493	0.5785	0.4304	0.1827
4.	Lighting, Freezers & Refrigerators	1.016	1.120	0.4441	0.7803	0.6892	0.5371	0.1827

Source and Comments: LTEAD[6]

"Elasticities for service demand for the period 1975 to 2000 were derived from service demand growth rates and GNP growth rates from the Hirst residential model. The 2020 value was based on the assumption that the elasticities for residential service demands would approach the ratio of population growth rate to GNP growth rate. These values were scaled linearly from 2000 to 2020 interval internally by the model."

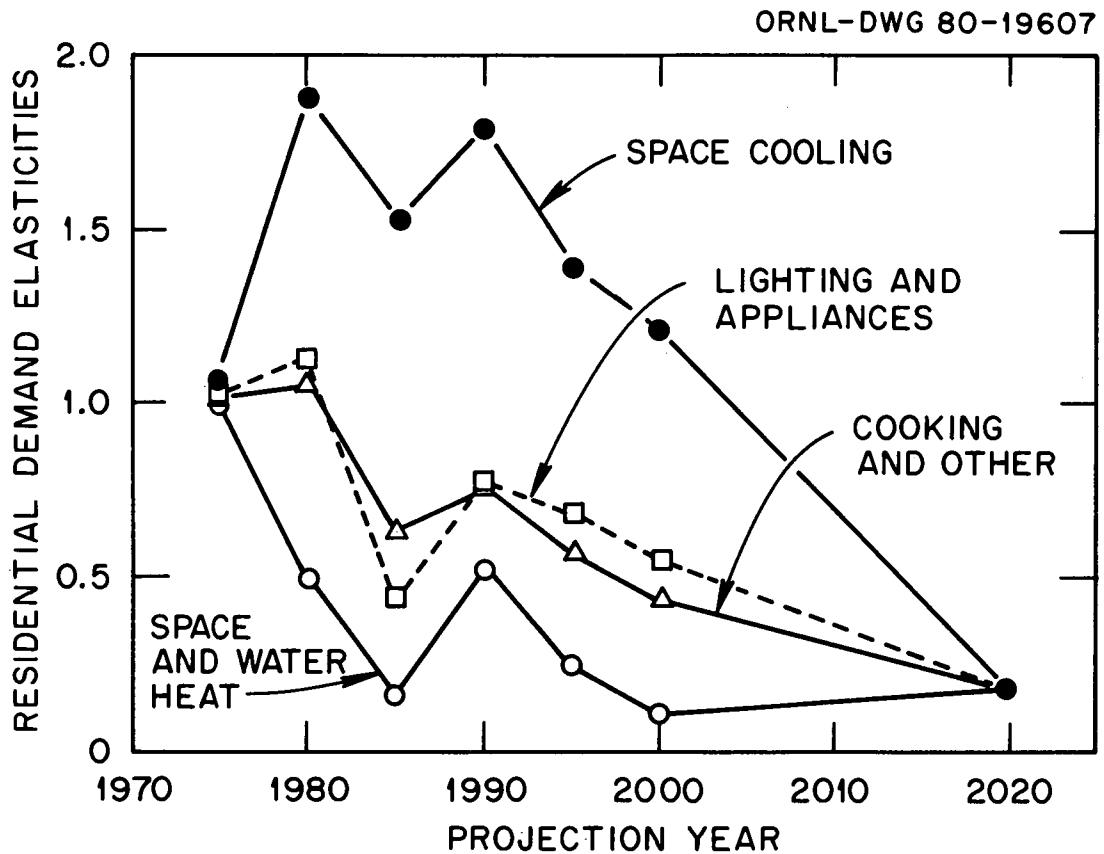


Fig. C.1. The Model 22C Demand Elasticities for the Residential Sector

APPENDIX C.2

MODEL 22C DATA BASE FOR THE INDUSTRIAL SECTOR

The Industrial Sector (as diagramed in Fig. A-2 of Ref. 4) contains an activity which represents the demand for eight types of industrial services. Three of these service demands are satisfied by multiple sources. They are:

a) direct heat, with four sources (oil, gas, low Btu gas, and coal),

b) indirect heat, with seven sources(low-Btu gas, high-Btu gas, heavy oil, coal, at. fluidized bed, solar (oil backup), and electricity),

c) electrical services with two sources (electric and electric autogeneration) where autogeneration is non-utility generated electricity.

In addition, there are three types of raw material demand (feedstock, met coal and lubes, waxes, asphalt) and two demands on the transportation sector (trucks, buses and rails, barge). Up to six of the activities could be characterized as representing new technologies. The demand elasticities were developed by the Long-Term Division from the ISTUM Industrial Demand Model[13] and from the MEFS[10] and Demand Analysis Division data. The majority of capital and operating costs were taken or derived from Brookhaven data.[9] The remainder were provided by the Conservation and Renewable Resource Division (CRRD)[7] or the Long-Term Division. Fuel shares for the allocators were calibrated to either the

ISTUM[13] or MEFS[10] 1995 forecasts or set by the Long-Term Division. Efficiency values were either derived from ISTUM data, taken from the Brookhaven report, or assigned by the Long-Term Division. Less significant parameters were obtained from Brookhaven data[9] or assigned by the Long-Term Division.

Table C.2.a contains the values of the allocation parameters and Table C.2.b includes the values of the basic conversion parameters for the industrial sector. The demand elasticities are tabulated in Table C.2.c and illustrated in Fig. C.2.

Table C.2.a. Industrial Sector; Allocation Parameters for Model 22C

1. Activity 2.4. Direct Heat

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) (%)			
		Light Oil	HBtu Gas	Coal	LBtu Gas
2.5	11.0	0.05	46.5	47.95	5.5

Source: LTEAD.[6] LTEAD comments:

"Fuel shares at equal prices are adjusted to calibrate 1995 forecasted shares against the ISTUM 1995 forecast, with an added adjustment to allow low-Btu gas to take approximately one-third of the market for gas-generated direct heat by the 1995-2000 period."

"This node was set to have a relatively inflexible allocation since some direct heat processes may demand a particular fuel, therefore not allowing a cheaper fuel to be substituted."

2. Activity 2.5. Indirect Heat

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) in Percent						
		Heavy Oil	HBtu Gas	LBtu Gas	Coal	AFB[a]	Solar	Heat Pump (Electric)
5.0	9.0	10.0	8.0	18.0	2.0	59.0	1.0	2.0

[a]Atmospheric Fluidized Bed.

Source: LTEAD.[6] LTEAD comments:

"Fuel shares at equal prices are adjusted to calibrate 1995 forecasted shares against the ISTUM 1995 forecast, with an added adjustment to allow low-Btu gas to take approximately one-third of the market for gas-generated indirect heat by 1995.

"No data was available for the penetration of solar as a new technology. Although AFB makes a significant contribution in the later years, solar does not because of its high price."

3. Activity 2.6. Indirect Geothermal

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) (%)	
		Indirect Heat[a]	Geothermal
5.0	9.0	90.0	10.0

[a]Boiler generated steam.

Source: LTEAD[6]. LTEAD comments:

"Geothermal heat competes on a price basis with 10 percent share assigned at equal prices because of the limitations of geography and temperature."

4. Activity 2.7. Electrical Services

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) (%)	
		Electricity from Utilities	Auto-Generation Electricity
5.0	9.0	96.0	4.0

Source: LTEAD[6]. LTEAD comments:

"Fuel shares at equal prices are adjusted to allow for approximately a one-half quad per year contribution by auto-generation throughout the time frame of the model."

5. Activity 2.8. Feedstock

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) (%)			TRANSI (Link differential) in $/MMBtu		
		Light Oil	HBtu Gas	NGL	Light Oil	HBtu Gas	NGL
2.5	11.0	37.0	19.0	44.0	0.76	1.75	0.73

Source: LTEAD.[6] LTEAD comments:

"The transportation increments were calculated by taking the difference between an arbitrary value ($5.00/MMBtu) and MEFS values for demand prices for industrial distillate, industrial gas and raw material sector liquids gases respectively. The fuel shares at equal prices are adjusted to calibrate the 1995 forecasted shares against the EIA mid-range 1995 forecast."

"This allocation node is set to be very inflexible, since it is assumed that the fuel requirements are based upon the nature of various chemical processes. Cheaper fuels may not be able to substitute."

6. Activity 2.28. Electricity Auto-Generation Replacement

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) (%)		
		Light Oil	HBtu Gas	Coal
5.0	9.0	66.98	33.00	0.02

Source: LTEAD.[6] LTEAD comments:

"The shares at equal prices are calibrated to produce two-thirds demand for high-Btu gas, the rest divided equally between light oil and coal as derived from the 1995 ISTUM forecast."

Table C.2.b. Industrial Sector: Basic Conversion Parameters for Model 22C

# Parameter	Indirect Heat Act. 2.3	Direct Heat Act. 2.10	Indirect Heat-Oil Act. 2.11	Direct Heat-Gas Act. 2.12	Indirect Heat-Gas Act. 2.13	Direct Heat-Low Btu Gas Act. 2.14	Direct Heat-Coal Act. 2.15	Indirect Heat-Coal Act. 2.16	Indirect Heat AFB-Coal Act. 2.17	Solar/Oil Backup Act. 2.18	Indirect Heat Electric Heat Pump Act. 2.19	Geothermal Act. 2.21	Electric Auto Generation Act. 2.22	Units
5 SCC	9.360[a]	0.2098[b]	3.200[c]	0.1498[d]	2.860[d]	6.540[a]	0.5900[d]	6.850[e]	17.44[f]	52.01[f]	1.670[g]	28.38[h]	8.270[i]	$/MMBtu/yr
7 VOC	0.6100[a]	0.0198[b]	0.2298[c]	0.0198[d]	0.1798[d]	0.4500[a]	0.0598[f]	0.3800[e]	1.510[f]	1.570[h]	0.0198[g]	1.510[h]	0.4900[j]	$/MMBtu
9 EFF	0.6000[a]	0.2918[j]	0.7500[j]	0.2968[j]	0.7500[j]	0.2379[a]	0.2998[j]	0.8200[k]	0.8200[j]	2.680[h]	1.000[j]	1.000[ℓ]	0.3440[j]	dimensionless
A-6 AVEFFI	1.000[ℓ]	0.2908[k]	0.7080[k]	0.2958[k]	0.6870[k]	1.000[j]	0.2988[k]	0.7000[k]	1.000[ℓ]	1.000[ℓ]	0.9410[j]	1.000[ℓ]	0.3440[j]	dimensionless
19 EFLIM	1.040[j]	1.130[j]	1.040[j]	1.180[j]	1.040[j]	1.176[j]	1.140[j]	1.000[j]	1.000[j]	1.000[j]	2.000[j]	1.000[ℓ]	1.750[j]	dimensionless
18 VOCRAT	0.05[j]	0.03[j]	0.03[j]	0.08[j]	0.05[j]	0.08[j]	0.07[j]	0.0098[m]	0.0198[m]	0.0098[m]	0.7000[j]	0.0098[m]	0.0600[j]	per year
30 QUAN1Y	0.0[j]	0.1748[j]	0.5880[j]	0.7100[j]	1.798[j]	0.0[n]	0.0708[j]	0.5830[j]	0.0[n]	0.0[n]	0.0178[j]	0.0[n]	0.4220[j]	quads/year
10 IPLTIM	8[d]	6[j]	6[j]	6[j]	6[j]	8[d]	8[j]	8[j]	10[j]	6[j]	4[j]	8[o]	3[j]	years
12 IYRAVL	1985[e]	1930[p]	1930[p]	1930[p]	1930[p]	1985[e]	1930[j]	1930[j]	1985[j]	1980[j]	1960[j]	1980[j]	1930[j]	year
14 CLIM	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	dimensionless
15 CRATE	0.0098[m]	0.0098[m]	0.0098[m]	0.0098[m]	0.0098[m]	0.0098[m]	0.0098[m]	0.0098[m]	0.0098[m]	0.0198[f]	0.0098[m]	0.0298[m]	0.0098[m]	per year
16 PRELIM	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	1.000[j]	dimensionless
22 ICLIFE	20[j]	25[j]	25[j]	25[j]	25[j]	20[d]	25[j]	25[j]	25[j]	20[h]	20[j]	30[j]	25[j]	years
24 ITXLIF	16[q]	20[q]	20[q]	20[q]	20[q]	16[q]	20[q]	20[q]	20[j]	16[q]	16[q]	24[r]	20[r]	years
25 IDLIFE	20[r]	25[j]	25[j]	25[j]	25[j]	20[r]	25[j]	25[j]	25[j]	20[j]	20[j]	30[r]	25[j]	years
29 EQFR	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	0.60[j]	$Equity/$Capital

FOOTNOTES

[a]BNL and LTEAD.

[b]BNL (distillate).

[c]BNL (RESID).

[d]BNL.

[e]BNL (median between high and low sulfur).

[f]No source provided.

[g]Source is given as "?".

[h]CRRD. Capital and operating costs were derived from the ISTUM data base by the Conservation and Renewable Resource Division in EIA.

[i]Derived from BNL.

[j]LTEAD.

[k]LTEAD. Derived from 1975 ISTUM model data.

[ℓ]Not applicable.

[m]Not used.

[n]LTEAD (not commercially available in 1975).

[o]BNL (electricity generation).

[p]DFI.

[q]LTEAD (0.8 ICLIFE).

[r]BNL (book life).

Table C.2.c. Industrial Sector; Demand Elasticities for Model 22C (dimensionless)

Node	Activity	Model Year 1975	1980	1985	1990	1995	2000	2020
1.	Direct Heat	1.000	0.4770	0.8521	1.618	1.000	0.8993	0.4967
2.	Indirect Heat (Geo)	1.000	0.8863	2.266	1.240	1.750	1.698	0.8753
3.	Electric Services	1.004	0.6589	1.739	1.409	1.571	1.508	0.7849
4.	Feedstock	1.000	1.173	1.207	1.553	1.500	1.431	0.7462
5.	Met Coal	1.000	0.0222	0.0537	0.3476	0.3570	0.2257	0.2257
6.	Lubes, Waxes, Asphalt	1.000	0.5338	0.3938	0.8798	0.9178	0.8116	0.4537
7.	Trucks and Buses	1.000	0.2951	0.4381	0.6566	0.4999	0.3977	0.3977
8.	Rail and Barge	1.000	0.5225	0.7930	0.4850	0.5356	0.4408	0.4408

Source and Comments: LTEAD[6]

"Elasticities for truck vehicle miles and freight ton miles for the period 1985 to 1995 were derived from MEFS and those prior to 1985 were obtained from the Demand Analysis Division. Elasticities for all other service demands in the industrial sector for the period 1975 to 1995 were derived from service demand growth rates and GNP growth rates from the ISTUM industrial model. The elasticities for metallurgical coal, truck vehicle miles, and freight ton miles were assumed to remain constant from 2000 to 2020. The 2000 values were derived using the 1995 service demand growth rate. The other service demand elasticities were assumed to be at half their 2000 value in 2020 due to the effect that higher prices would have on increasing conservation efforts in certain technologies. The values were scaled linearly from 2000 to 2020; the scaling being internal to the model."

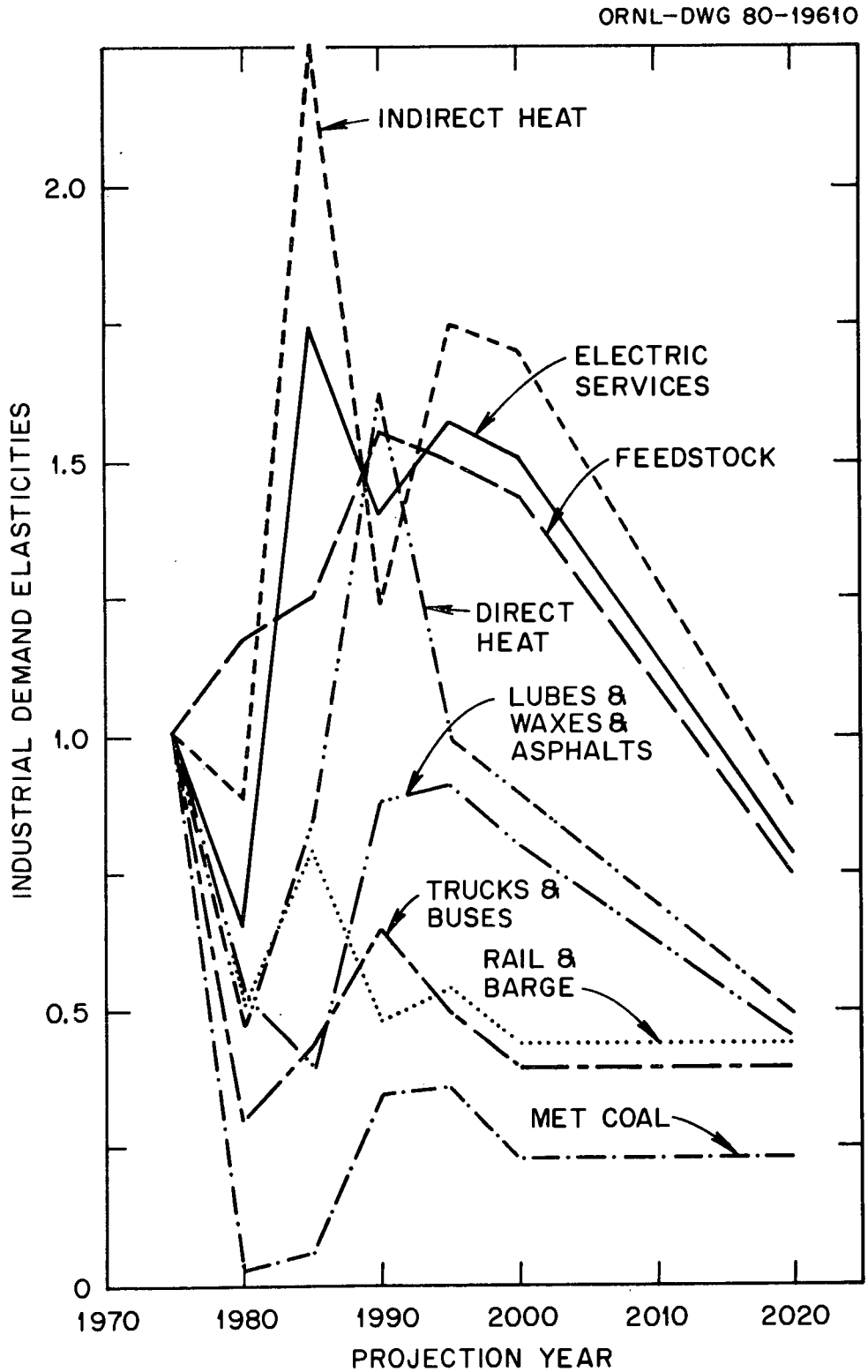


Fig. C.2. The Model 22C Demand Elasticities for the Industrial Sector.

Appendix C.3

MODEL 22C DATA BASE FOR THE DISTRIBUTION SECTOR

The distribution sector provides energy to the demand sectors, residential, industrial, transportation, and commercial, except for natural gas liquids which are fed directly from the oil and gas sector to industry (see Fig. A-3 of Ref. 4). Only three parameters appear in the Model 22C data base for the distribution sector. TRANSI is used for Activities 3.1 through 3.5 and VOC and EFF are implemented for Activities 3.6 and 3.7. Therefore, the tables for the distribution sector are ordered differently from those in other sectors.

TRANSI "reflects distribution charges by including a price differential derived from a wholesale price and the various retail prices." (Ref. 2). As a constant differential which must be added for each model year, it is not possible to implement the inflation rate $\neq 0.0$ option without recoding LEAP.

Table C.3.a. contains the tabular values for TRANSI and Table C.3.b. includes the data for VOC (Variable Operating Cost) and EFF (Thermal Efficiency). First the activities in the distribution sector are defined:

3.1. Light Oil Allocation
3.2. Heavy Oil Allocation
3.3. Gas Allocation
3.4. Electricity Allocation
3.5. Coal Allocation
3.6. Electric Line Loss
3.7. Metallurgical Coal Transport

Table C.3.a. Distribution Sector: TRANSI Parameters for Model 22C in ($/MMBtu)

Activity	Utilities	Residential	Commercial	Industrial	Transportation
3.1	0.0	0.81	0.55	0.56	1.51
3.2	0.0	0.26	0.18	0.28	--
3.3	0.0	0.66	0.24	0.32	--
3.4	--	1.82	1.83	-1.02	1.98
3.5	0.0	--	--	0.2199	--

Source: LTEAD[6]

For all except activity 3.4, the wholesale and retail prices were obtained from MEFS Series C, 1995 listing. For activity 3.4 the retail prices were obtained in the same manner but, "The wholesale price was taken from the LEAP output value for electric power loading, 30th iteration."

Table C.3.b. Distribution Sector; VOC and EFF Parameters for Model 22C

Activity	VOC $/MMBtu	EFF (dimensionless)	Source
3.6	0.0	0.9	LTEAD[a]
3.7	0.3098	1.0	LTEAD[b]

[a]MEFS Series C 1995 data.

[b]"No losses assumed."

APPENDIX C.4

MODEL 22C DATA BASE FOR THE ELECTRICITY SECTOR

The Electricity Sector (as diagramed in Fig. A-6 of Ref. 4) contains fourteen separate technologies for the centralized production of electric power (conventional nuclear, advanced nuclear, coal boiler, low-med Btu gas with combined cycle, MHD, atmospheric fluidized bed, oil boiler, oil turbine, fuel cell oil, gas boiler, gas turbine, biomass, hydro and central renewables). Each technology is represented as a source of electricity generation for base, intermediate, and peak load categories. Seven of the fourteen processes represented are new technologies. Data for the two nuclear technologies were supplied for the most part by the Nuclear Energy Analysis Division. Basic data for all other technologies were provided by the Coal and Electric Power Analysis Division. The Long-Term Division, DFI,[3] and Brookhaven[9] were sources for a limited number of parameters.

Table C.4.a contains the values of the allocation parameters and Table C.4.b includes the electric power loading parameters for the electricity sector. The electric power conversion parameters are tabulated in Table C.4.c.

Table C.4.a. Electricity Sector; Allocation Parameters for Model 22C

Activity No.	Description	SHSENS (dimensionless)	BELAG (Years)
4.1	Electricity Allocation[a] (Utilities)	10.0	5.0
4.2	Uranium Fuel Allocation	10.0	5.0
4.3	Light Oil Allocation (Electricity)	5.0	9.0
4.4	Gas Allocation (Electricity)	5.0	9.0
4.14	Coal Allocation (Electricity)	5.0	9.0

Source and Comments: LTEAD

[a] "Relative penetration of each technology was based on the cost of that technology. A lag term was used for a smooth entrance of new technologies."

Table C.4.b. Electricity Sector; Electric Power Loading Parameters for Model 22C

Activity No.	Description	ENFRC (Energy Loading Fractions) (percent)		
		Base	Intermediate	Peak
4.5	Electric Power Loading	91.74	7.49	0.75

Source: LTEAD[6]

Table C.4.c. Electricity Sector: Basic Conversion Parameters for Model 22C

No.	Parameter	Advanced Nuclear (LMFBR) Act. 4.6	Conventional Nuclear (LWR) Act. 4.7	Coal Boiler Act. 4.8	Oil Boiler Act. 4.9	Oil Turbine Act. 4.10	Gas Boiler Act. 4.11	Gas Turbine Act. 4.12	Central Renew-ables Act. 4.13	Low-Med-Btu Gas Com-bined Cycle Act. 4.15	AFB Act. 4.16	Fuel Cell Act. 4.17	Biomass (Elec) Act. 4.19	MHD Act. 4.20	Units
5	SCC	47.70[a]	24.32[b]	14.19[c]	11.51[c]	4.760[c]	8.510[c]	4.760[c]	35.64[d]	19.59[c]	18.15[c]	10.83[c]	27.34[c]	18.37[c]	$/MM Btu/yr
7	VOC	0.9700[b]	0.6800[b]	1.030[c]	1.000[e] (0.32)	0.500[c]	1.500[e] (0.32)	0.500[c]	4.000[e] (0.26)	0.529[c]	1.320[c]	0.7600[c]	5.570[c]	0.5600[c]	$/MM Btu
9	EFF	0.3998[b]	0.3198[b]	0.3700[c]	0.3599[c]	0.2398[c]	0.3599[c]	0.2398[e]	0.3599[f]	0.3800[c]	0.3498[c]	0.3599[c]	0.3098[c]	0.4500[c]	Dimensionless
A-6	AVEFFI	1.000[g]	0.3098[h]	0.3308[i]	0.3198[i]	0.2348[j]	0.3198[i]	0.2348[j]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	Dimensionless
19	EFLIM	1.000[b]	1.000[b]	0.9500[c]	1.210[c]	1.240[c]	1.210[c]	1.240[c]	1.000[c]	1.000[c]	1.000[c]	1.230[c]	1.000[c]	1.000[c]	Dimensionless
18	VOCRAT	0.0[b]	0.0[b]	0.0098[c]	0.9800E-02[c]	0.1980E-01[c]	0.1000E-01[c]	0.2000E-01[c]	0.0000[f]	0.0[k]	0.0[ℓ]	0.3980E-01[c]	0.5000E-01[f]	0.0[ℓ]	Per year
30	QUANTY	0.0[m] 0.0[d] 0.0[d]	0.5900[b] 0.0[b] 0.0[b]	2.650[f] 0.2399[f] 0.1490E-01[f]	0.9050[f] 0.8190E-01[f] 0.4900E-02[f]	0.0[f] 0.0[f] 0.9800E-02[f]	0.9330[f] 0.8490E-01[f] 0.4900E-02[f]	0.0[f] 0.0[f] 0.9800E-02[f]	0.0[c] 0.0[c] 0.0[c]	0.0[m] 0.0[m] 0.0[m]	0.0[m] 0.0[m] 0.0[m]	0.0[m] 0.0[m] 0.0[m]	0.0[m] 0.0[m] 0.0[m]	0.0[m] 0.0[m] 0.0[m]	B quads/yr I quads/yr P quads/yr
10	IPLTIM	15[a]	13[a]	12[c]	12[c]	4[c]	12[c]	4[c]	12[c]	10[c]	10[c]	4[c]	8[c]	18[c]	Years
12	IYRAVL	2010[a]	1970[b]	1930[n]	1930[n]	1950[n]	1945[c]	1950[n]	1995[c]	1990[c]	1990[c]	1985[c]	1990[c]	2005[c]	Year
14	CLIM	0.9000[b]	0.9000[b]	1.250[c]	2.000[e] (0.73)	1.000[c]	2.000[e] (0.85)	1.000[c]	1.000[c]	1.000[c]	1.000[c]	1.000[c]	0.800[c]	1.000[c]	Dimensionless
15	CRATE	0.2980E-01[b]	0.2980E-01[b]	0.1980E-01[c]	0.1000[e] (0.07)	0.0[ℓ]	1.000[e] (0.04)	0.0[ℓ]	0.0[?]	0.0[ℓ]	0.0[ℓ]	0.0[ℓ]	0.1980E-01[c]	0.0[ℓ]	Per year
16	PRELIM	1.000[b]	1.000[b]	1.250[f]	1.250[e] (1.0)	1.000[p]	1.250[e] (1.0)	1.000[p]	1.000[f]	1.000[f]	1.000[f]	1.000[f]	1.400[f]	1.000[f]	Dimensionless
20	AVAIL	0.7000[a]	0.8000[a]	0.7900[c]	0.8000[c]	0.8900[c]	0.8000[c]	0.8900[c]	0.8500[c]	0.7800[c]	0.7800[c]	0.9200[c]	0.8000[c]	0.6600[c]	Dimensionless
21	LOADFC	0.8800[q] 0.4980E-01[q] 0.4980E-01[q]	0.8800[r] 0.5000[r] 0.4980E-01[r]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.9000E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.9000E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	0.8100[c] 0.5000[c] 0.8980E-01[c]	B dimensionless I dimensionless P dimensionless
22	ICLIFE	30[a]	30[a]	30[s]	30[c]	30[c]	30[c]	30[c]	30[t]	30[s]	30[c]	30[c]	30[c]	30[c]	Years
24	ITXLIF	16[a]	16[a]	24[c]	24[c]	24[c]	24[c]	24[c]	24[c]	24[c]	24[c]	24[c]	24[c]	24[c]	Years
25	IDLIFE	30[b]	30[b]	30[s]	30[s]	30[s]	30[s]	30[s]	30[c]	30[c]	30[s]	30[s]	30[s]	30[s]	Years
29	EQFR	0.4500[b]	0.4500[b]	0.4500[s]	0.4500[s]	0.4500[s]	0.4500[s]	0.4500[s]	0.4500[s]	0.4500[c]	0.4500[s]	0.4500[s]	0.4500[s]	0.4500[s]	$ Equity/$ Capital

NOTES: The values given in parenthesis were supplied by the Coal and Electric Power Division. Activity 4.18 (Hydro/Geothermal) - - Basic Conversion Process Parameters are not provided since this node is a dummy. That is, the quantities of electricity produced are input by the modeler. Further LTEAD comments: "Estimates of electrical generation produced by geothermal sources were obtained from MEFS Series C, for 1985, 1990, and 1995. Electrical generation from hydro was assumed constant at 1.046 quads (EPRO Data Base) throughout this period. From 2000 to 2020, electrical output from hydro/geothermal was assumed constant based on preliminary results of the National Energy Plan 2 (NEP 2)." Although the prices of hydro and geothermal electricity are calculated in the allocation process (Activity 4.1), the quantities are transferred unmodified through every iteration.

FOOTNOTES

[a] NEAD (Nuclear Energy Analysis Division, EIA)
[b] BNL & NEAD
[c] NEAD (PEAK is not used)
[d] LTEAD (CEPAD)
[e] CEPAD (solar thermal)
[f] CEPAD (Coal and Electric Power Analaysis Division, EIA)
[g] Not used if CLIM is equal to 1.0
[h] Not applicable
[i] LTEAD, ARC '78 Vol. II
[j] LTEAD - 1975 energy balance
[k] LTEAD, ARC '78 Vol. II & Edison Elec. Inst. Data
[ℓ] CEPAD & LTEAD
[m] NEAD (INTERMEDIATE & PEAK are not used)
[n] LTEAD
[o] BNL
[p] DFI
[q] LTEAD - not available in 1975
[r] Not used
[s] Not used when PRELIM, POSTLIM & EFLIM equal to 1.0
[t] DFI & CEPAD

Further LTEAD Comments

Act. 4.6 – for Advanced Nuclear (LMFBR) ..."It was assumed that the breeder would operate essentially in base load. Although the breeder uses plutonium which results from the LWR, it was assumed here to be fueled entirely by uranium. Calculations were based on a 1200 MWE plant operating at 65% capacity factor."

Act. 4.7 – for Conventional Nuclear (LWR) ..."The LWR was assumed to operate in base or intermediate load categories. Calculations were based on a 1200 MWE plant operating at 65% capacity factor."

Act. 4.8 – for Coal Boiler ..."Capital and operating costs increase over time to reflect the cost of scrubbers. A slight decrease in efficiency occurs for the same reason. Calculations were based on a 800 MWE plant with a Wellman Lord SO2 Removal System."

Act. 4.9 – for Oil Boiler ..."In order to phase out oil-fired boilers due to regulation, a penalty was placed on its capital and operating costs. Initial operating costs were assumed to be $1.00/MMBtu increasing in the limit to $1.25/MMBtu. Capital costs were assumed to increase by a factor of 2 with a 10% per year increase toward that limit. The data in parentheses were the actual numbers supplied by the Coal and Electric Power Analysis Division."

Act. 4.11– for Gas Boiler ..."Initial operating costs were assumed to be $1.50/MMBtu increasing on the limit to $1.88/MMBtu. Capital costs were assumed to increase by a factor of 2 with a 10% per year increase toward that limit."

Act. 4.13– for Central Renewables ..."A high variable operating cost was assumed to constrain the penetration of these technologies due to restrictions on sites and the storage problems of wind-generated power. As a result, electricity produced by renewables was constrained to 0.5 quads in 2020."

Act. 4.15, 4.16, 4.20 – for Low-Med Btu Gas with Combined Cycle, Atmospheric Fluidized Bed (AFB) and MHD ..."Technological costs were assumed constant since it was unclear whether they would increase or decrease over time."

Act. 4.19– for Biomass (Electricity) ..."The cost of the fuel input was included in the variable operating cost of this process. The operating costs were assumed to increase over time, constraining penetration to represent limitations on the availability of fuel. This was accomplished by increasing the operating costs by a limiting factor of 1.4, assuming a 5% per year increase toward that limit after the year of commercial availability. As a result, electricity produced by biomass was constrained to 0.21 quads in 2020."

NOTE: The capital and operating costs for the fuel cell (Act. 4.17) seem abnormally low; no comments for this activity were provided by LTEAD.

Appendix C.5

MODEL 22C DATA BASE FOR THE NUCLEAR SECTOR

This sector is treated very superficially in that uranium is milled and mined as a resource under Activity 5.1 and enriched and transported to the utilities under Activity 5.2. No other activities are included. The fast breeder reactor has been given a specific input data base in the electricity sector, but it is "assumed" to be fueled by uranium. The nuclear sector is diagrammed in Fig. A-5 of Ref. 4.

Since the input data for Model 22C have little impact as chosen for this sector, the effort expended here is only to provide documentation of the values employed. Although the fast breeder reactor should be treated separately, further study would be required to determine whether different input parameters would have significantly affected the output. Certainly, the nuclear sector should be studied in more detail than allowed for Model 22C.

The resource parameters for Activity 5.1 are given in Table C.5.a., and those for transportation/enrichment (Activity 5.2) are presented in Table C.5.b.

Table C.5.a. Nuclear Sector; Resource Parameters for Model 22C

#	Parameter	Uranium Mining and Milling[a] Act. 5.1	Units
10	IPLTIM	8[b]	years
12	IYRAVL	1955[c]	year
14	CLIM	1.000[b]	dimensionless
15	CRATE	0.0698[d]	per year
16	PRELIM	1.000[c]	dimensionless
18	VOCRAT	0.0[d]	per year
22	ICLIFE	20[b]	years
25	IDLIFE	15[b]	years
20	EQFR	0.6500[b]	$Equity/$Capital
30	QUANIY	1.900[b]	quads/year
40	INRCST	0.3198[b]	$/MMBtu
41	BASEPR	0.5000[b]	$/MMBtu
42	UNRCRS	1310[b]	quads
43	NEWRS2	1750[b]	quads
44	CCCF	0.5[b]	dimensionless
47	DCLNO	0.05[e]	per year
53	TRMULT	2.1998[f]	dimensionless
31	RATIN	0.0[g]	per year

[a]Mining and milling of yellow cake.

[b]NEAD (Nuclear Energy Analysis Division of the EIA). Additional comments by LTEAD: "The data ... are consistent with the Mid-Term Energy Market Model (MEMM) fuel supply curves for 1995, Series C."

"The Btu values are for the thermal input to light water reactors of the fuel produced from the yellow cake."

[c]LTEAD.

[d]Labeled as "not applicable."

[e]Model calculated as (= 1/ICLIFE).

[f]No source provided.

[g]"GLOBAL"

Table C.5.b. Transportation/Enrichment (Activity 5.2) Parameters for Model 22C

VOC	(Variable Operating Cost)	0.64	($/MMBtu)
EFF	(Thermal Efficiency)	1.0	(dimensionless)

Sources: NEAD

"The data were provided by the Nuclear Energy Analysis Division of EIA and are consistent with the MEMM 1995, Series C data."

Additional LTEAD Comments:

"A cost of 3.66 miles per kWhr of thermal input to light water reactors was provided to the equivalent value of $0.34 per million Btu of thermal input, a penalty of $0.30 per million Btu was added to inhibit moderately the rate of penetration of nuclear power. The $0.30 equated the cost in 2000 of base load electricity generated using the light water reactor and the coal-fired boiler for power."

"This node represents the cost of the balance of the fuel cycle services: conversion, enrichment, fabrication."

APPENDIX C.6

MODEL 22C DATA BASE FOR THE COAL SECTOR

The Coal Sector (as diagramed in Fig. A-6 of Ref. 4) includes coal resources, synthetic liquid and gas production and synthetic gas transportation. The resources are divided into six coal types from three regions (Western, Mid-Continent and Appalachian). The resource data were produced by the Long-Term Division from data supplied by the Coal and Electric Power Division from the National Coal Model. The synthetic plant capital costs and other values come from the Brookhaven data base,[9] which is an upgraded and expanded EPRI data base.[8] The synthetics plant operating costs and efficiencies come from a DOE study (See NEP-II[11]). A cost increment calculated by the Long-Term Division was added to western synthetic gas and liquid production to represent a water charge in that region. The transportation values were derived by the Long-Term Division from BNL[9] and EIA data, and equal price shares were derived from MEFS.[10]

Table C.6.a contains the values of the allocation parameters and Table C.6.b includes the high-Btu gas transport parameters for the Coal Sector. The coal resource parameters and the basic conversion parameters for the Coal Sector are tabulated in Tables C.6.c and C.6.d, respectively.

Table C.6.a. Coal and Coal Products Allocation Parameters for Model 22C

1. Coal (SHSENS = 12.5; BELAG = 3 years)

Activity	Parameter	Western Low Sulfur	Western M/HS	Mid Continent	Appalach. M/HS	Appalach. LS	Units
6.1	FREQPR	31.58	19.98	24.68	21.38	0.218	Percent
	TRANSI	0.80	0.93	0.34	0.19	0.0	$/MMBtu

Source: LTEAD[6]. Additional LTEAD comments.

"Cost increments are added to the price of each source of coal to compensate for differences in transportation costs and quality. The Equal Price Shares were equated to the percent output for each category in MEFS 1995 Case C."

"The cost increments are the differences between the average 1995 mine prices of each source of coal and the delivered price to utilities of the MEFS Series C estimate of March 23, 1979."

"The parameters of the allocator are set to permit rapid shifts in market shares of the coal sources in response to changes in relative costs."

Table C.6.a. Coal and Coal Products Allocation Parameters for Model 22C (Cont'd)

2. Coal Liquids (SHSENS = 12.5; BELAG = 3 years)

Activity	Parameter	Western Low Sulfur	Western M/HS	Mid Continent	Appalach. M/HS	Units
6.2	FREQPR	25.0	25.0	25.0	25.0	Percent
	TRANSI	0.0798	0.0798	0.0298	0.0298	$/MMBtu

Source: LTEAD. Additional LTEAD comments

"The cost increments are based on BNL crude pipeline costs and estimated distance to a major refining center " (for TRANSI).

"The parameters of the allocator are set to permit rapid shift in market shares of the sources in response to changes in relative costs."

Table C.6.a. Coal and Coal Products Allocation Parameters for Model 22C (Cont'd)

3. High-Btu Syngas (SHSENS = 5.0; BELAG = 9.0)

Activity	Parameter	Western Low Sulfur	Western M/HS	Mid Continent	Appalach. M/HS	Units
6.3	FREQPR	25.0	25.0	25.0	25.0	Percent
	TRANSI*	0.0	0.0	0.0	0.0	$/MMBtu

Source: Not given. LTEAD comments.

"The parameters of this allocator are set to permit a relatively slow response of market share to changes in the relative prices of high Btu gas from the four sources. This rate of response did not affect results significantly."

*TRANSI is zero since the TRANSPT module is used to include transportation charges for each coal supply listed above.

Table C.6.a. Coal and Coal Products Allocation Parameters for Model 22C (Cont'd)

4. High Quality Coal (SHSENS = 12.5; BELAG = 3 years)

Activity	Parameter	Appalach. Premium	Appalach. LS	Appalach. M/HS	Units
6.22	FREQPR	70.0	9.98	19.98	Percent
	TRANSI	0.5400	0.5800	0.9600	$/MMBtu

Source: LTEAD. Additional Comments by LTEAD.

"Cost increments are added to each of the prices to represent transportation cost and quality differences."

"The cost differences are based on MEFS 1995 and equal the differences between the cost of metallurgical coal to industry and the average prices at the mine of the three coals."

"High quality coal is primarily metallurgical coal. (Some nonmetallurgical coal is exported.)"

"The parameters of the allocator are set to allow a fairly rapid response to price."

Table C.6.b. Coal Sector: Basic Conversion Parameters for Coal Liquefaction and Gasification for Model 22C

No.	Parameter	Liquids Production Mid-Cont. Act. 6.10	High-Btu Gas Production Mid-Cont. Act. 6.11	Liquids Production Western Low Sulfur Act. 6.12	High-Btu Gas Production Western Low Sulfur Act. 6.13	Liquids Production Appalachian M/H Sulfur Act. 6.14	High Btu Gas Production M/H Sulfur Act. 6.15	Liquids Production Western M/H Sulfur Act. 6.25	High Btu Gas Production M/H Sulfur Act. 6.26	Units
5	SCC	10.76[a]	11.68[b]	11.01[a]	10.89[c]	10.76[a]	11.68[b]	10.76[a]	11.68[b]	$/MMBtu/yr
7	VOC	0.9200[d]	1.240[d]	1.180[d]	1.290[d]	0.9200[d]	1.240[d]	1.180[d]	1.290[d]	$/MMBtu
9	EFF	0.7000[e]	0.7200[e]	0.7000[e]	0.7500[e]	0.7000[e]	0.7200[e]	0.7000[e]	0.7500[e]	Dimensionless
A-6	AVEFFI	1.000[f]	1.000[f]	1.000[f]	1.000[f]	1.000[f]	1.000[g]	1.000[f]	1.000[f]	Dimensionless
19	EFLIM	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	Dimensionless
18	VOCRAT	0.0[h]	0.0[h]	0.0[h]	0.0[h]	0.0[h]	0.0[f]	0.0[h]	0.0[h]	Per year
30	QUANTY	0.0[i]	0.0[i]	0.0[i]	0.0[i]	0.0[i]	0.0[i]	0.0[i]	0.0[i]	Quads/year
10	IPLTIM	8[j]	8[j]	8[j]	8[j]	8[j]	8[j]	8[j]	8[j]	Years
12	IYRAVL	1995[g]	1995[g]	1995[g]	1995[g]	1995[g]	1995[g]	1995[g]	1995[g]	Year
14	CLIM	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	Dimensionless
15	CRATE	0.0498[h]	0.0498[h]	0.0498[h]	0.0498[h]	0.0498[h]	0.0498[h]	0.0498[h]	0.0498[h]	Per year
16	PRELIM	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[g]	1.000[h]	1.000[g]	1.000[g]	Dimensionless
22	ICLIFE	20[k]	20[ℓ]	20[ℓ]	20[ℓ]	20[ℓ]	20[ℓ]	20[ℓ]	20[ℓ]	Years
24	ITXLIF	16[m]	16[m]	16[m]	16[m]	16[m]	16[m]	16[m]	16[m]	Years
25	IDLIFE	20[o]	20[n]	20[n]	20[g]	20[n]	20[n]	20[n]	20[n]	Years
29	EQFR	0.6000[g]	0.4500[g]	0.6000[g]	0.4500[o]	0.6000[g]	0.4500[g]	0.6000[g]	0.4500[g]	$ Equity/ $ Capital

FOOTNOTES

[a]BNL, Syncrude from HS/HBtu coal

[b]BNL, HBtu gas (2nd Gen) from HS/HBtu coal

[c]BNL, HBtu gas (2nd Gen) from LS/LBtu coal

[d]NEP-2 & LTEAD

[e]NEP-2

[f]Not applicable

[g]LTEAD

[h]Not used

[i]LTEAD (not available in 1975)

[j]BNL, modified

[k]From BNL book life

[ℓ]LTEAD, from BNL book life

[m]LTEAD (0.8 ICLIFE)

[n]LTEAD (same as ICLIFE)

[o]Same as ICLIFE

Additional LTEAD Comments:

Act. 6.10. Liquids Production from Mid-Continent Coal.

"The specific capital cost is based on BNL data which used a capacity of 250 MMM Btu/day. The variable operating cost and efficiency are based on NEP-2 data, and includes the cost of upgrading to syncrude. NEP-2 used a capacity of 360 MMM Btu/day."

"Second generation processes are represented. This technology becomes available in 1995, meaning that commercial production with no early introduction penalty begins after 1990 to scale up to the 1995 level. This industry is assumed to be unregulated so 60 percent equity financing is used."

Act. 6.11. High Btu Gas Production from Mid-Continent Coal.

"The specific capital cost is from BNL data. The variable operating cost and efficiency are from NEP-2 data."

"Advanced technology is represented. This technology becomes available in 1995, meaning that commercial production with no early introduction penalty begins after 1990 to scale up to the 1995 level. The plant capacity used by BNL and NEP-2 is 250 MMM Btu/day."

"This industry is assumed to be regulated, so the electric utility percent equity is used."

Act. 6.12. Liquids Production from Western Low-Sulfur Coal.

"The specific capital cost is from BNL data which used a capacity of 250 MMM Btu/day. The variable operating cost and efficiency are based on NEP-2 data, except that 26¢ per million Btu has been added to the operating cost for water supply. The assumed water cost is three times as large as the pipeline cost of the syncrude, on the assumptions that three barrels of water are required per barrel of product and the shipping distances are comparable. NEP-2 used a capacity of 360 MMM Btu/day."

"Second generation technology is represented. This technology becomes available in 1995, meaning that commercial production with no early introduction penalty begins after 1990 to scale up to the 1995 level."

"This industry is assumed to be unregulated so 60 percent equity financing is used."

Act. 6.13. High Btu Gas Production from Western Low-Sulfur Coal.

"The specific capital cost is from BNL data. The variable operating cost and efficiency are from NEP-2 data, with 35¢ per million Btu added to the operating cost as an assumed charge for bringing the required water from a distance."

Additional LTEAD Comments (Cont'd)

Act. 6.13. (Cont'd)

"Advanced technology is assumed. This technology becomes available in 1995, meaning that commercial production with no early introduction penalty befins after 1990 to scale up to the 1995 level. The plant capacity used by BNL and NEP-2 is 250 MMM Btu/day."

"This industry is assumed to be regulated so the electric utility percent is used."

Act. 6.14. Liquids Production from Appalachian Med-High Sulfur Coal.

"The specific capital cost is from BNL data. BNL used a capacity of 250 MMM Btu/day. The variable operating cost and efficiency are from NEP-2 data. The NEP-2 report stated a capacity of 360 MMM Btu/day."

"Advanced technology is represented. This technology becomes available in 1995, meaning that commercial production with no early introduction penalty begins after 1990 to scale up to the 1995 level."

"This industry is assumed to be unregulated, so 60 percent equity financing is used."

Act. 6.15. High Btu Gas Production from Appalachian Med-High Sulfur Coal.

"The specific capital cost is from BNL data. The variable operating cost and efficiency are from NEP-2 data."

"Advanced technology is represented. This technology becomes available in 1995, meaning that commercial production with no early introduction penalty begins after 1990 to scale up to the 1995 level. The plant capacity used by BNL and NEP-2 is 250 MMM Btu/day."

"This industry is assumed to be regulated, so the electric utility percent equity is used."

Act. 6.25. Liquids Production from Western Med-High Sulfur Coal.

"The specific capital cost is from BNL data. BNL used a capacity of 250 MMM Btu/day. The variable operating cost and efficiency are from NEP-2 data. A charge for transporting the required water from a distance is added on the basis of BNL liquids pipeline costs and the assumption that 3 barrels of water are required per barrel of output. The NEP-2 report used a capacity of 360 MMM Btu/day."

"Advanced technology is represented so the year available is deferred until 1995, which permits commercial production after 1990."

"This industry is assumed to be unregulated so an equity finance fraction of 60 percent is used."

Additional LTEAD Comments (Cont'd)

Act. 6.26. High Btu Gas Production from Western Med-High Sulfur Coal

"The specific capital cost is from BNL data. The variable operating cost and efficiency are from NEP-2 data. A charge of 35¢ per million Btu for transporting the water required from a distance is added to the variable operating cost on the basis of BNL liquids pipeline data and the assumption that 0.6 barrels of water per MCF of output are required."

"Advanced technology is represented so the year available is deferred until 1995, which permits production after 1990. The plant capacity used by BNL and NEP-2 is 250 MMM Btu/day."

"This industry is assumed to be regulated, so the electrical utility finance fraction is used."

Table C.6.c. Coal Production Resource Parameters for Model 22C

No.	Parameter	Western Low Sulfur Act. 6.16	Appalachian High Sulfur Act. 6.17	Mid Continent Act. 6.18	Appalachian Low Sulfur Act. 6.19	Western Med-High Sulfur Act. 6.23	Appalachian Premium[a] Act. 6.24	Units
10	IPLTIM	10[b]	8[b]	8[b]	8[b]	8[b]	8[b]	Years
12	IYRAVL	1930[b]	1930[c]	1930[c]	1930[c]	1930[b]	1930[b]	Year
14	CLIM	1.109[d]	1.200[d]	1.200[d]	1.200[d]	1.109[d]	1.200[d]	Dimension-less
15	CRATE	0.0698[d]	0.0698[d]	0.0698[d]	0.0698[d]	0.0698[d]	0.0698[d]	Per year
16	PRELIM	1.000[b]	1.000[b]	1.000[b]	1.000[b]	1.000[b]	1.000[b]	Dimension-less
18	VOCRAT	0.0[b]	0.0[b]	0.0[b]	0.0[b]	0.0[b]	0.0[b]	Per year
22	ICLIFE	25[b]	30[b]	30[b]	30[b]	25[b]	30[b]	Years
25	IDLIFE	15[b]	15[b]	15[b]	15[b]	15[b]	15[b]	Years
29	EQFR	0.6500[b]	0.6500[b]	0.6500[b]	0.6500[b]	0.6500[b]	0.6500[b]	$ Equity/ $ Capital
30	QUAN1Y	1.060[b]	6.880[b]	3.260[b]	0.7000[b]	0.8000[b]	1.900[b]	Quads/yr
40	INRCST	0.3538[e]	0.9780[e]	0.6860[e]	1.060[e]	0.3278[e]	1.175[e]	Dimension-less
41	BASEPR	0.4419[e]	0.9920[e]	0.7780[e]	1.250[e]	0.4098[e]	1.356[e]	$/MMBtu
42	UNRCRS	131.5[e]	43.20[e]	90.00[e]	12.60[e]	221.7[e]	150.0[e]	Quads
43	NEWRS2	630.4[e]	1200.[e]	750.[e]	46.50[e]	451.2[e]	510.0[e]	Quads
44	CCCF	0.5000[e]	0.5000[e]	0.5000[e]	0.5000[e]	0.5000[e]	0.5000[e]	Dimension-less
47	DCLNO	0.0400[f]	0.0333[f]	0.0333[f]	0.0333[f]	0.0400[f]	0.0333[f]	Per year
53	TRMULT	1.5998[g]	1.2498[g]	1.2498[g]	2.000[g]	1.5998[g]	1.2498[g]	Dimension-less
31	RATIN	1.0[h]	0.0211[h]	0.0224[h]	0.0276[h]	1.0[h]	0.0258[h]	Per year

FOOTNOTES

[a]This coal is assumed to be used only for metallurgical purposes.

[b]LTEAD.

[c]DFI.

[d]LTEAD & CEPAD.

[e]These parameters were developed concurrently by LTEAD as indicated in the text.

[f]Calculated internally, 1 over ICLIFE.

[g]No source provided.

[h]"GLOBAL"

Further LTEAD Comments:

"The supply curve is derived primarily from data supplied by the Coal and Electric Power Division developed from the National Coal Model, and additional National Coal Model (NCM) data provided by I.C.F. Inc. The model parameters represent a curve fitted to these data and extrapolated beyond the demonstrated coal reserve base boundary of the NCM."

"The characteristic facility life and the increase in capital costs are based on discussions with the Coal and Electric Power Division."

"The equity financial fraction of 65 percent was used for all resource development."

The following comment applies to all activities except Activity 6.18:

"The demonstrated coal reserve base data of the NCM does not cover a sufficient portion of coal resources to properly represent all coal mines to be opened (committed to production) through 2020. Therefore, the basic data were extrapolated in the form of the exponentially rising cost curve used by LEAP."

Table C.6.d. High-Btu Gas Transport Parameters for Model 22C

1. Activity 6.7. Mid-Continent Coal

Parameter	Description	Value	Units	Source
VOC	Variable Operating Cost	0.0868	$/MMBtu	BNL
EFF	Thermal Efficiency	0.98	Dimension-less	LTEAD

LTEAD Comments:

"This node represents the cost of pipeline transportation of mid-continent synthetic natural gas and the portion of the gas used as pipeline or process fuel.

Data sources

The variable operating cost is based on BNL data, assuming 300 miles from plant to market.

Comments

The thermal efficiency is 1 minus the percent of gas used. Pipeline use is a ratio of the 300 mile distance over an assumed 1000 mile average times the average use of 3%. An additional 1% was added to calibrate the 1975 data."

Table C.6.d. High-Btu Gas Transport Parameters for Model 22C (Cont'd)

2. Activity 6.8. Western Low Sulfur Coal

Parameter	Description	Value	Units	Source
VOC	Variable Operating Cost	0.2908	$/MMBtu	BNL
EFF	Thermal Efficiency	0.96	Dimension-less	LTEAD

LTEAD Comments:

"This node represents the cost of pipeline transportation of western synthetic natural gas and the portion of the gas used as pipeline or process fuel.

Data sources

The variable operating cost is based on BNL data, assuming 1000 miles from plant to market. The thermal efficiency is 1 minus the percent of fuel used.

The percentage of input used for fuel is set at the national average of 3%, with an additional 1% added to calibrate to 1975 Data."

Table C.6.d. High-Btu Gas Transport Parameters for Model 22C (Cont'd)

3. Activity 6.9. Appalachian Med-High Sulfur Coal

Parameter	Description	Value	Units	Source
VOC	Variable Operating Cost	0.0868	$/MMBtu	BNL
EFF	Thermal Efficiency	0.98	Dimension-less	LTEAD

LTEAD Comments:

"This node represents the cost of pipeline transportation of Appalachian synthetic natural gas and the portion of the gas used as pipeline or process fuel.

Data sources

The variable operating cost is based on BNL data, assuming 300 miles from plant to market. The thermal efficiency is 1 minus the percent fuel used. Pipeline fuel as a percent is the 300 mile distance over an estimated 1000 mile average times the national average of 3%. An additional 1% was added to calibrate to 1975 data."

Table C.6.d. High-Btu Gas Transport Parameters for Model 22C (Cont'd)

4. Activity 6.27. Western Med-High Sulfur Coal

Parameter	Description	Value	Units	Source
VOC	Variable Operating Cost	0.0868	$/MMBtu	BNL
EFF	Thermal Efficiency	0.98	Dimension-less	LTEAD

LTEAD Comments:

"This node represents the cost of transportation of western synthetic natural gas to market, and the portion of the gas used as pipeline or process fuel.

Data Sources

The variable operating costs are from BNL data, assuming a 1000 mile distance. The percent of input used for pipeline fuel is set at the U.S. average of 3%, with an additional 1% added to calibrate to 1975 data."

APPENDIX C.7

MODEL 22C DATA BASE FOR THE OIL AND GAS SECTOR

The Oil and Gas Sector (as diagramed in Fig. A-7 of Ref. 4) contains activities representing oil and gas production, refining and transportation. The production is divided among Domestic, Alaskan and Enhanced Recovery for both oil and gas. Shale oil is also included as a production activity. Inputs from imports and synthetics are incorporated where appropriate.

Most of the basic values which defined the resource supply curves were provided by the Oil and Gas Division and/or USGS circular 725[14] and were modified somewhat by the Long-Term Division. Equal price shares, where needed, were derived by the Long-Term Division from the MEFS[10] data base. Basic refinery data were obtained from the Brookhaven report[9] or derived by the Long-Term Division. The majority of the transportation values were obtained by the Long-Term Division from MEFS[10] or Brookhaven[9] data. Other sources used in the oil/gas sector were reports from the Bureau of Mines, Department of Interior,[15] and Lewin and Associates.[16]

Table C.7.a contains the values of the allocation parameters and Table C.7.b includes the basic conversion parameters for the oil refining process. The oil and gas resource parameters and the transportation parameters for the oil/gas sector are tabulated in Tables C.7.c and C.7.d, respectively.

Table C.7.a. Oil and Gas Sector. Allocation Parameters for Model 22C

Activity 7.1

1. Refined Oil

SHSENS (dimensionless)	BELAG (years)	TRANSI (Transportation Increments in $/MMBtu) Heavy	Light	NGL	FREQPR (Equal Price Shares in %) Domestic Refining	Imported Products
5.0	20.0	-0.19	0.28	0.87	100.0	0.01

Source and Comments: LTEAD[6]

"This allocator controls the relative market shares of imported and domestic oil products. The allocator parameters are assigned values which allow a very slow rate of response of market share to relative price. This was done to inhibit product imports."

"All increments are based on the average refinery acquisition costs of MEFS. The heavy oil increment equals the MEFS price of residual fuel to utilities less the refinery acquisition cost of crude. The light oil increment uses the price of distillate to utilities and the NGL increment is the price of LPG feedstock to industry relative to the same base."

"The resulting prices are overstated by the average cost of refining, which should have been deducted in calculating the cost increments."

"The equal price shares were set with a minimal share for refined import to force the major imports to be crude oil."

Activity 7.2

2. Dry Gas*

SHSENS (dimensionless)	BELAG (years)	FREQPR (Equal Price Shares) in Percent			
		Domestic Conventional	EGR	North Slope Gas	Imports
5.0	7.0	74.1	10.0	7.5	8.4

*Source and Comments: LTEAD[6]

"This is a pure allocator with no price increments. This allocator controls the overall rate of change of the market shares of the four input sources of gas. The parameters are assigned values which permit a moderate rate of response of market shares to changes in relative prices. This prevents natural gas from new sources from penetrating too rapidly."

Activity 7.3

3. Crude Oil*

SHSENS (dimensionless)	BELAG (years)	TRANSI (Transportation Increments) in $/MMBtu				
		Shale	Alaskan Oil	EOR	Imports	Domestic
5.0	15.0	0.11	0.23	0.06	0.01	0.07

FREQPR (Equal Price Shares) in Percent				
Shale	Alaskan Oil	EOR	Imports	Domestic
20.0	20.0	20.0	20.0	20.0

*Source and Comments: LTEAD[6]

"The parameters of the allocator are assigned values which severely limit the rate of response of market shares to changes in relative prices. This limits the rates of development of new sources of crude oil."

"The purpose of the cost increments is to approximate the average cost of delivering each type of crude to the average U.S. refinery and to adjust for quality differentials."

Activity 7.8

4. Syncrude Penetration[a]

SHSENS (dimensionless)	BELAG (years)	TRANSI (Transportation Increments) in $ Syncrude	TRANSI (Transportation Increments) in $ Crude	FREQPR (Equal Price Shares) in % Syncrude	FREQPR (Equal Price Shares) in % Crude
5.0	15.0	0.15	0.0	50.0	50.0

[a]Source and Comments: LTEAD[6]

"The parameters of the allocator are assigned values which inhibit the rate of change of market shares in response to relative prices. This limits the rate of growth of syncrude output."

Activity 7.9

5. Synthetic Gas Penetration[b]

SHSENS (Dimensionless)	BELAG (years)	TRANSI (Transportation Increments) in $/MMBtu Dry Gas	TRANSI (Transportation Increments) in $/MMBtu Syn. Gas from Coal	FREQPR (Equal Price Shares in %) Dry Gas	FREQPR (Equal Price Shares in %) Syn. Gas from Coal
7.5	7.0	0.0	0.0	50.0	50.0

[b]Source and Comments: LTEAD[6]

"The parameters are assigned moderate values which permit a moderate rate of response of market shares to relative prices, since the rate of development of synthetic gas is not excessive."

Table C.7.b. Oil Refining: Basic Conversion Parameters for Model 22C

No.	Parameter	Act. 7.4	Units
5	SCC	1.510[a]	$/MMBtu/yr
7	VOC	0.0999[a]	$/MMBtu
9	EFF	0.9200[b]	dimensionless
A-6	AVEFFI	0.9050[b]	dimensionless
19	EFLIM	1.000[b]	dimensionless
18	VOCRAT	0.0[b]	per year
30	QUAN1Y	26.14[b]	quads/year
10	IPLTIM	8[c]	years
12	IYRAVL	1930[b]	year
14	CLIM	1.000[b]	dimensionless
15	CRATE	0.0298[d]	per year
16	PRELIM	1.000[b]	dimensionless
22	ICLIFE	20[b]	years
24	ITXLIF	16[b]	years
25	IDLIFE	20[b]	years
29	EQFR	0.6000[b]	$ Equity/$ Capital

[a] BNL[9]

[b] LTEAD[6]

[c] BNL, modified

[d] Not used

Further LTEAD Comments:

"The cost of upgrading shale oil to crude oil quality is included under Section 7, Activity 16."

"Adjustments for crude oil quality differentials were included in the price increments applied in crude oil allocation and syncrude penetration."

Table C.7.c. Oil and Gas Production; Resource Parameters for Model 22C

#	Parameter	Enhanced Oil Recovery	Enhanced Gas Recovery	Shale Oil Mining & Retorting	North Slope Oil	Domestic Oil & NGL	North Slope Gas	Domestic Gas (Cont. US)	Units
		Act. 7.6	Act. 7.7	Act. 7.10	Act. 7.11	Act. 7.12	Act. 7.13	Act. 7.14	
10	IPLTIM	1[a]	1[a]	8[a]	1[a]	1[a]	1[a]	1[a]	years
12	IYRAVL	1985[a]	1985[a]	1990[a]	1975[a]	1930[a]	1985[a]	1945[a]	year
14	CLIM	1.000[a]	1.000[a]	1.000[a]	1.000[a]	1.000[a]	1.000[a]	1.000[a]	dimensionless
15	CRATE	0.0[b]	0.0[b]	0.0698[b]	0.0[b]	0.0[b]	0.0[b]	0.0[b]	per year
16	PRELIM	1.000[a]	1.000[a]	1.000[a]	1.000[a]	1.000[a]	1.000[a]	1.000[a]	dimensionless
18	VOCRAT	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]	per year
22	ICLIFE	15[a]	40[a]	30[a]	30[a]	30[a]	30[a]	30[a]	years
25	IDLIFE	10[a]	27[a]	15[a]	20[a]	20[a]	20[a]	20[a]	years
29	EQFR	0.6500[a]	0.6500[a]	0.6500[a]	0.6500[a]	0.6500[a]	0.6500[a]	0.6500[a]	$Equity/$Capital
30	QUAN1Y	0.0[c]	0.0[c]	0.0	0.0[a]	20.21[a]	0.0[a]	18.39[a]	quads/year
31	RATIN	0.1998[d]	0.1998[d]	0.0[d]	0.1998[d]	0.1998[d]	0.1998[d]	0.1998[d]	per year
40	INRCST	1.850[e]	1.750[e]	2.140[e]	1.200[e]	1.600[e]	1.000[e]	0.9517[e]	$/MMBtu
41	BASEPR	2.170[e]	1.940[e]	2.570[e]	2.170[e]	2.170[e]	2.100[e]	2.122[e]	$/MMBtu
42	UNRCRS	86.00[e]	84.00[e]	58.00[e]	121.0[e]	308.0[e]	57.50[e]	361.0[e]	quads
43	NEWRS2	182.0[e]	173.0[e]	464.0[e]	186.2[e]	473.0[e]	88.50[e]	555.0[e]	quads
44	CCCF	0.500[e]	0.600[e]	0.700[e]	0.800[e]	0.800[e]	0.800[e]	0.800[e]	dimensionless
47	DCLNO	0.200[a]	0.050[a]	0.333[b]	0.0998[g]	0.1338[a]	0.0998[g]	0.1148[a]	per year
53	TRMULT	1.40[h]	1.7199[h]	1.4699[h]	2.160[h]	1.880[h]	3.820[h]	3.820[h]	dimensionless

FOOTNOTES

[a] LTEAD[6]

[b] "Not used"

[c] LTEAD (not available in 1975)

[d] "GLOBAL"

[e] These parameters were developed concurrently by LTEAD as indicated in the text

[f] Calculated internally, 1 over ICLIFE

[g] DFI[3]

[h] No source given

Additional LTEAD Comments

Activity 7.6 Enhanced Oil Recovery

"The values provided by the Oil and Gas Division were: initial resource cost, $1.52 (1975 dollars), base price, $2.17; undiscovered recoverable resources at the base price, 108.5 quads; and 181.5 quads at double the base price. These data apply to additional recovery from known reservoirs, which is sufficient for mid-range analysis since the lag between discovery and enhanced recovery is about 20 years.

The quantities were adjusted as follows:

- 46 quads were added to the amount recoverable at twice the base price, to allow for EOR from 1/2 of the potential new discoveries on the onshore continental U.S.

- Both quantities were then reduced by 20 percent on the assumption that a maximum of 80 percent of the potential EOR would be developed by 2020. The decline rate is based on the assumption that individual EOR facilities will be depleted rather quickly."

Activity 7.7 Enhanced Gas Recovery

"The quantity available at double the base price is 80 percent of the total of Lewin's base quantity from the two sources and one-half of that which might be added through advanced technologies. The quantity available at the base price is derived from a curve fitted to the Lewin data as adjusted above.

The 1985 year available permits initial production after 1980, the low decline rate is based on the assumption that EGR facilities will produce at a low rate for an extended period of time."

Activity 7.10 Shale Oil-Mining & Retorting

"The new resource at twice the base price is limited to the 80 billion barrels of shale oil estimated to be recoverable from the highest quality resources on the assumption that the costs of meeting air quality standards will limit total production. The quantity at the base price is 10 billion barrels, the amount of resources required to be developed when production equals 1 million bb/d. At this level of output, it is assumed that water will have to be delivered from a substantial distance.

For the initial resource cost, an average upgrading cost of $3 per barrel was deducted from the $18 per barrel figure provided by the Oil and Gas Division (both in 1978 dollars).

The base price was obtained by adding $0.43 per MMBtu to the initial resource cost to cover the cost of bringing water from a distance. It was assumed that the rising cost curve thereafter would reflect the increasing cost of mining and meeting air quality standards.

This technology becomes available in 1990, meaning that commercial production with no early introduction penalty begins after 1985 to scale up to the 1990 level.

It is assumed that a shale oil mining and retorting facility can produce at a constant rate over the characteristic life, so the deposit decline rate is internally calculated as 1 over ICLIFE."

Activity 7.11 North Slope Oil Production

"Production from the two areas in Alaska--the southern region and the North Slope--are not disaggregated in this model. The quantity at twice the base price is equal to 75 percent of the total resources of the North Slope and the inferred and undiscovered resources of the rest of Alaska. Since much of the undiscovered recoverable resources are subject to Arctic conditions, higher costs are assumed for the remaining 25 percent.

Measured reserves of the North Slope are included because production had not begun in 1975. The statistical means of undiscovered resources are used.

The quantity available at the base price is set at 2/3 of the quantity at twice the base price.

The decline rate was set the same as North Slope natural gas."

Activity 7.12 Domestic Oil and Associated Gas Production

"To calculate the quantity at twice the price, the sum of indicated, inferred, and undiscovered recoverable resources (USGS circular #725 statistical mean as amended) for 1975 is increased by 15 percent to include natural gas liquids. Then the quantity at twice the price is set at 85 percent of this total. The remaining 15 percent is assumed to be undiscovered in 2020 because of the random nature of the discovery process and/or higher costs.

The quantity at the base price is set at 2/3 of the quantity at twice the base price.

The decline rate was calculated as a ratio of production to reserves for 1977."

Activity 7.13 North Slope Gas

"The quantity available at twice the base price is assumed to be 75 percent of the total of North Slope proved reserves of natural gas plus inferred and undiscovered recoverable resources for all of Alaska. The proved North Slope reserves are included because production had not begun in 1975. The remaining 25 percent is assumed to be more expensive to produce because of the Arctic location of these resources.

The quantity available at the base price was set at 2/3 of the quantity at twice the base price.

The 1985 year available allows production to begin after 1980.

The 10% decline rate is a standard assumption for natural gas."

Activity 7.14 Domestic Gas Production

"The quantity available at twice the base price is 85 percent of the total of inferred resources and the statistical mean of undiscovered recoverable resources as amended. The quantity at the base price is set at 2/3 of that at twice the base price. The remaining 15 percent is assumed to be undiscovered in 2020 and/or to have a higher cost.

The decline rate was calculated as a ratio of production to reserves for 1977."

Table C.7.d. Oil and Gas Sector. Transport Parameters for Model 22C

#	Parameter	Shale Oil Upgrade & Transport[a] Act. 7.16	North Slope Oil Transp. to U.S. Act. 7.17	Enhanced Gas Recovery Transport[b] Act. 7.18	North Slope Gas Transport Act. 7.19	Imported Gas Transport Act. 7.20	Non-Associated Gas Transport Act. 7.22
7	VOC ($/MMBtu)	0.45	0.72	0.240	0.700	0.0	0.260
9	EFF	0.95	1.00	0.886	0.816	0.978	0.886
54	DIST (unit miles)	--	1.00[c]	--	1.00[c]	--	--

Sources and Comments: LTEAD[6]

[a]"The cost of upgrading at $3.00 per barrel in 1978 dollars is $0.435 per million Btu (in 1975 dollars) which was rounded to $0.45. (See Shale Oil Mining and Retorting)

A Bureau of Mines Report (TPR-81, September 1974) shows 52,350 b/d of input to upgrading was required to yield 50,000 b/d of partially refined crude. The resulting 95.5 percent efficiency was rounded to 95 percent."

[b]"The plant and field use factor was calculated for 1975 production and assumed to be applicable to EGR at the same value."

[c]Labeled "not used".

APPENDIX C.8

MODEL 22C DATA BASE FOR THE TRANSPORTATION SECTOR

The Transportation Sector (as diagramed in Fig. A-8 of Ref. 4) contains a demand for personal transportation consisting of aircraft passenger miles and two types of automobile vehicle miles (conventional oil cars and electric cars). Two other activities are linked to industrial demand, truck/bus vehicle miles, and rail/barge ton miles. Values for demand were obtained from the Demand Analysis Division, calibrated to MEFS,[10] or assumed by the Long-Term Division. Most capital and operating costs were obtained from Brookhaven[9] and efficiencies resulted from combining MEFS[10] and Department of Transportation data. Other less significant data were obtained from Brookhaven or assumed by the Long-Term Division.

Table C.8.a contains the values of the allocation parameters and Table C.8.b includes the basic conversion parameters for the transportation sector. The demand elasticities for the transportation sector are tabulated in Table C.8.c and illustrated in Fig. C.8.

Table C.8.a. Transportation Sector; Allocation Parameters for Model 22C

Activity #	SHSENS (dimension-less)	BELAG (years)	FREQPR (Shares at Equal Price) in Percent			
			Auto Oil	Auto Electric	Heavy Oil	Light Oil
8.8	10.0	10.0	85.0	15.0	-	-
8.9	10.0	5.0	-	-	45.0	55.0

Activity #	Description
8.8	Vehicle Mile Allocation[a]
8.9	Freight Fuel Allocation[b]

[a]Output is auto vehicle miles for personal transportation demand. LTEAD[6] Comments:

"Data came from several sources including DOT, DOE, and other articles."

"Electric cars are assumed to replace conventional cars only for a certain portion of urban vehicle miles. In 1975, urban driving was 58% of total vehicle miles. Fractions at equal prices are set at 85% conventional/ 15% electric, reflecting a LTEAD assumption that electric cars could capture about one quarter of the urbran vehicles miles (15/58% = 26%)."

[b]Output is freight fuel for freight transportation.

Table C.8.b. Transportation Sector: Basic Conversion Parameters for Model 22C

#	Parameter	Aircraft Including Military Act. 8.1	Auto (oil) Act. 8.2	Trucks and Buses Act. 8.3	Auto (Electric) Act. 8.6	Rail, Barge and other Freight Act. 8.7	Units
5	SCC	0.1608[a]	0.5299[a]	6.6200[b]	0.7700[c]	0.0898[d]	$/mile/yr[e]
7	VOC	0.0128[a]	0.1798[f]	4.000[b]	0.0998[c]	0.0298[a]	$/mile[e]
9	EFF	0.1228[g]	0.1043[h]	0.0668[g]	0.2000[i]	0.9980[g]	miles/(1000 Btu)[e]
A-6	AVEFFI	0.1228[i]	0.1043[i]	0.0668[i]	1.0000[j]	0.9460[i]	miles/(1000 Btu)[e]
19	EFLIM	1.440[i]	4.500[i]	1.510[i]	1.200[i]	1.110[i]	dimensionless
18	VOCRAT	0.0598[i]	0.0350[i]	0.0828[i]	0.0298[i]	0.0198[i]	dimensionless
30	QUAN1Y	0.1626[k]	1.050[ℓ]	0.2808[k]	0.0[m]	1.327[i]	10^{12} miles/year[e]
10	IPLTIM	5[i]	2[i]	4[i]	10[i]	4[i]	years
12	IYRAVL	1930[i]	1930[i]	1930[i]	2000[i]	1930[i]	year
14	CLIM	1.000[a]	1.000[i]	1.000[a]	1.000[i]	1.000[a]	dimensionless
15	CRATE	0.0098[n]	0.0098[n]	0.0098[o]	0.0198[o]	0.0098[o]	dimensionless
16	PRELIM	1.000[i]	1.000[i]	1.000[i]	1.000[i]	1.000[i]	dimensionless
22	ICLIFE	15[i]	10[i]	15[i]	10[i]	25[i]	years
24	ITXLIF	10[a]	5[i]	10[i]	5[i]	17[a]	years
25	IDLIFE	15[a]	3[i]	5[i]	3[i]	25[a]	years
29	EQFR	0.1998[a]	0.0998[i]	0.7000[i]	0.0998[i]	0.5000[a]	$ Equity/$ Capital

[a]BNL

[b]Derived from BNL

[c]LTEAD[6] - derived from several independent estimates

[d]BNL - aggregation of rail and barge costs

[e]These units are specified to explicitly describe the Model 22C input parameters even though they are inconsistent among themselves and with the available documentation[2] (see the comments which follow). From the energy use for 1975, it was determined that QUANTY must be in trillion (10^{12}) miles/year. Therefore, SCC and VOC should be multiplied by 10^3 and defined as $/1000 miles/year and $/1000 miles, respectively, in order to make the Model 22C Data Base units consistent in this sector.

[f]EPRI[8] - from BNL report; also FHWA

[g]Derived from MEFS[10] and DOT

[h]Derived from MEFS[10] and DOT data

[i]LTEAD[6]

[j]Not applicable

[k]MEFS[10] - Demand Group

[ℓ]MEFS[10] - Demand Group - from DOT

[m]LTEAD - vehicle miles insignificant in 1975

[n]Not used

[o]No source given

Additional LTEAD Comments:

Activity 8.1. Aircraft

"The output is billion passenger air miles."

"Most of the technical data came from Brookhaven. Efficiencies were estimated based on present information of passenger miles/Btu and estimated future changes. The initial price of $3.34 is MEFS price in 1975."

Activity 8.2. Auto (Oil)

"The output quantity is stated in vehicle miles of travel."

". . .The efficiency is chosen to correspond to 13.1 mpg and assumed to increase to 34 mpg by 2020. The 13.1 mpg differs from the Federal Highway Administration number of 13.7 because LEAP fuel input was 10.05 quads, which includes .5 quad of off-highway gasoline. Otherwise, using a 9.55 quad figure results in 13.7 mpg. These are fleet average figures—tracking MEFS through 1990. The variable operating cost is based on EPRI estimates and agrees with published FHWA data for a new model car (costs include operating, maintenance, and depreciation)."

Activity 8.3. Trucks and Buses

"The output is stated in vehicle miles."

"The Brookhaven data were used as guidance in estimating costs and efficiencies although bus travel was not included and the units were reported per ton-mile, not vehicle mile. The $4.16 initial price is a weighted average of diesel and gasoline prices according to shares consumed in 1975."

"Bus vehicle miles account for a very small amount of the total (less than 2%). The truck vehicle miles are for what Department of Transportation (DOT, FHWA) categorizes as "cargo vehicles"—both single unit trucks and combinations. The bus miles are both commercial and school buses."

Activity 8.6. Auto (Electric)

"The output is in vehicle miles."

"Specific capital cost and variable operating costs were from Brookhaven. Year commercially available (2000), thermal efficiency (twice that of gas cars on a Btu basis), and operating initial change rate are all very conservative DOE/EIA estimates that explain the minimal penetration of electric cars in LEAP through 2020."

Activity 8.7. Rail, Barge and Other Freight

"The output is in freight-ton miles."

"DOT estimates of 1975 rail and marine ton-miles were used. The price is a weighted average of the three fuel types. The operating and capital costs came from Brookhaven."

Table C.8.c. Transportation Sector; Demand Elasticities

Node	Activity	Model Year 1975	1980	1985	1990	1995	2000	2020
1	Air Passenger Miles	1.000	0.5907	0.7338	0.7253	0.4999	0.3977	0.3977
2	Auto Vehicle Miles	1.000	0.7726	1.083	1.206	1.250	1.077	0.1827

Source and Comments: LTEAD[6]

"Elasticities for service demands from 1985 to 1995 were derived from MEFS and those prior to 1985 were obtained from the Demand Analysis Division. The 2000 value for air passenger miles was derived using the 1995 service demand growth rates and the 2000 elasticity was assumed through 2020."

"Due to the assumption of automobile saturation, the elasticity for auto vehicle miles in 2020 was assumed to trend to the ratio of population to GNP growth. These elasticities were scaled linearly from 1995 to 2020; the scaling being internal to the model from 2000 to 2020."

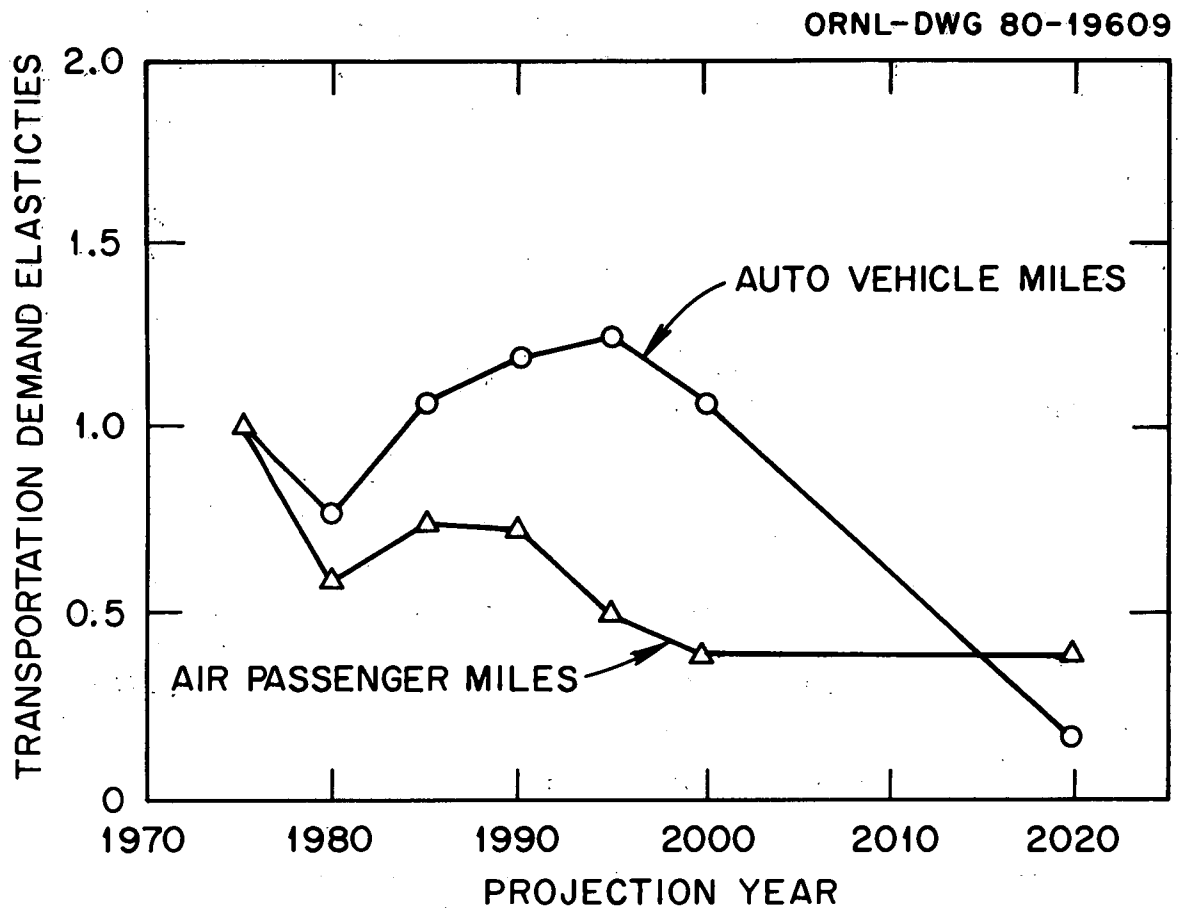


Fig. C.8. The Model 22C Demand Elasticities for the Transportation Sector

APPENDIX C.9

MODEL 22C BASE FOR THE COMMERCIAL SECTOR

The Commercial Sector (as diagramed in Fig. A-9 of Ref. 4) contains a demand activity, combined space and water heat (from five sources), space cooling (from two sources), electrical services (from two sources) other electric and other gas. The demand elasticities are developed from the Structural Commercial Energy Use (Jackson) model[17] for the first five periods and extrapolated linearly to values assumed by the Long-Term Division for the remaining periods. Capital and operating cost and some efficiency data were developed from Brookhaven[9] values. Other efficiency data, equal price shares, and 1975 initial conditions were developed from Jackson model data.[17] Other less significant values originated with DFI,[3] Brookhaven[9] or the Long-Term Division.

Table C.9.a contains the values of the allocation parameters and Table C.9.b includes the basic conversion parameters for the commercial sector. The demand elasticities for the commercial sector are tabulated in Table C.9.c and illustrated in Fig. C.9.

Table C.9.a. Commercial Sector; Allocation Parameters for Model 22C

1. Activity 9.1. Heat and Water

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) in Percent				
		Light Oil	Gas	Electricity	Solar	Heavy Oil
5.0	9.0	0.2	21.6	78.0	0.01	0.20

Source and Comments: LTEAD[6]

"Penetration of solar heat is not adequately accounted for due to lack of data."

2. Activity 9.15. Cool Allocation

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) in Percent	
		Electric Cooling	Solar Cooling
5.0	9.0	90.0	9.99

Source and Comments: LTEAD[6]

"The shares at equal prices are set to default values. That allows only negligible penetration of solar cooling due to its high cost."

3. Activity. 9.17. Electric Service Allocation

SHSENS (dimensionless)	BELAG (years)	FREQPR (Shares at Equal Prices) in Percent	
		Electricity (conventional)	Electricity Photovoltaics & Wind
5.0	9.0	90.0	9.99

Source and Comments: LTEAD[6]

"The shares at equal prices are set to default values. That allows only negligible penetration of distributed electricty due to siting, storage and other limitations on use."

Table C.9.b. Commercial Sector: Basic Conversion Parameters for Model 22C

#	Parameter	Light Oil Heater Act.9.3	Gas Heater Act.9.4	Solar Heat and Geothermal Act. 9.5	Electric Heater Act. 9.6	Lighting & Other Appliances Act. 9.7	Other Electric Act.9.8	Other Gas Act. 9.9	Electric Cool Act. 9.13	Solar Cool Act.9.14	Distributed Electric[a] Act. 9.16	Heavy Oil Heater Act. 9.18	Units
5	SCC	31.15[b]	24.94[b]	165.5[c]	10.87[b]	0.0[d]	18.02[e]	20.27[b]	37.84[f]	200.0[d]	208.0[d]	31.15[g]	$/MMBtu/yr
7	VOC	0.7100[b]	0.5800[b]	1.210[c]	0.4900[b]	0.0[d]	0.0[b]	0.0[b]	0.3398[f]	1.300[d]	0.7400[d]	0.7100[g]	$/MMBtu
9	EFF	0.6480[h]	0.6000[h]	4.000[i]	1.050[d]	1.000[d]	1.000[b]	1.000[d]	2.400[b]	2.000[i]	1.000[i]	0.6480[d]	dimension-less
A-6	AVEFFI	0.6480[d]	0.6080[d]	1.000[i]	1.050[d]	1.000[d]	1.000[d]	1.000[d]	2.400[d]	1.000[i]	1.000[i]	0.6480[d]	dimension-less
19	EFLIM	1.260[d]	1.350[d]	1.100[i]	1.610[d]	1.000[d]	1.000[d]	1.000[d]	1.330[d]	1.050[i]	1.000[i]	1.260[d]	dimension-less
18	VOCRAT	0.1500[d]	0.1000[d]	0.0100[i]	0.0900[d]	0.0100[d]	0.0100[i]	0.0100[i]	0.1200[d]	0.0098[i]	0.0098[i]	0.1500[d]	per year
30	QUANIY	0.6500[d]	1.110[d]	0.0[d]	0.1098[d]	0.6000[d]	0.1798[d]	0.1500[d]	1.440[d]	0.0[j]	0.0 [j]	0.6200[d]	quads/year
10	IPLTIM	3[d]	3[d]	6[d]	3[d]	3[d]	3[d]	3[d]	3[d]	6[d]	5[d]	3[d]	years
12	IYRAVL	1930[k]	1930[k]	1975[d]	1930[k]	1930[k]	1930[k]	1930[k]	1965[d]	1985[d]	1985[d]	1930[k]	year
14	CLIM	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	dimension-less
15	CRATE	0.0098[ℓ]	0.0098[ℓ]	0.0498[ℓ]	0.0098[ℓ]	0.0098[d]	0.0098[ℓ]	0.0098[i]	0.0098[i]	0.0098[i]	0.0198[i]	0.0098[i]	per year
16	PRELIM	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	1.000[d]	dimension-less
22	ICLIFE	30[d]	20[d]	20[d]	20[d]	20[d]	20[d]	20[d]	20[d]	20[d]	25[d]	30[d]	years
24	ITXLIF	24[m]	16[m]	16[m]	16[m]	24[m]	16[m]	16[m]	16[m]	16[m]	20[m]	24[m]	years
25	IDLIFE	30[d]	20[d]	20[d]	20[d]	20[d]	20[d]	20[d]	20[d]	20[d]	25[d]	30[d]	years
29	EQFR	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	0.6000[d]	$ Equity/ $ Capital

FOOTNOTES

[a] This node represents the generation of electric power by distributed processes such as photovoltaics and wind.

[b] BNL[9]

[c] Derived from BNL[9]

[d] LTEAD[6]

[e] BNL[9] - miscellaneous resistance heat

[f] BNL[9] - (central unit)

[g] BNL[9] - (high load factor)

[h] LTEAD[6], equals average efficiency

[i] Not applicable

[j] Not commercially available in 1975

[k] DFI[3]

[ℓ] Not used

[m] LTEAD[6] (0.8 ICLIFE)

Additional LTEAD[6] Comments:

Activity 9.5. Solar Heat and Geothermal

"No provision is made for the decrease that will occur in the capital cost of solar systems. Also, no allowance is made for either a gas or an electric backup to the solar system."

Activity 9.6. Electric Heater

"Hirst and Jackson allocate Master Metered apartments to residential from commercial."

Activity 9.7. Lighting and Other Appliances

"No capital or operating costs were used since the node competes with no other to provide services. Also, efficiency was assumed to be 1.0 and demand is expressed in terms of Btu input."

Activity 9.8. Other Electric and Other Gas

"Efficiency was assumed to be 1.0 and demands are expressed in terms of Btu input."

Activity 9.14. Solar Cooling

"No allowance is made for the decrease in capital cost that is likely to occur as solar systems are developed. Also, no provision is made for a backup to the solar system."

Activity 9.16. Distributed Electric

"No provision is made for the decrease in capital cost that will occur as photovoltaic systems are further developed and manufactured."

Activity 9.18. Heavy Oil Heater

"Commercial use of coal, which is not considered separately, is included here."

Table C.9.c. Commercial Sector; Demand Elasticities for Model 22C (Activity 9.10)

	1975	1980	1985	1990	1995	2000	2020
A) Heat & Water	0.9406	0.9090	0.5357	0.8627	0.6213	0.5638	0.6429
B) Cooling	1.012	1.057	1.186	1.398	1.125	1.049	0.6429
C) Lighting & Appliances	1.009	0.6998	0.5919	0.8386	0.7357	0.7453	1.000
D) Other Electric	1.021	1.621	1.236	1.041	0.9035	0.9071	1.000
E) Other Gas	0.9904	0.8931	0.5002	0.2790	0.1570	-0.0152	-0.0152

Sources and Comments: LTEAD[6]

"The elasticities of service demand with respect to GNP from 1975 through 2000 are derived from preliminary results of the structural commercial energy use (Jackson) model, adjusted to the 1995 demand levels of the final results of the same model."

"The 2020 elasticities are based on assumptions by the Long-Term Division as to the behavior of demand beyond 2000."

"The upward adjustment of the space heat and hot water elasticities appears to have been excessive. The 2020 elasticity is derived from an average of the adjusted elasticities."

"The 2020 elasticity of space cooling is set equal to that of space heat and hot water on the assumption that the demand for air conditioning will be saturated by them."

"The 2020 growth in demand for light and other electric services is set equal to the growth in GNP to allow for the expanded use of office equipment and other electrical devices. The elasticity of other use of gas is held constant."

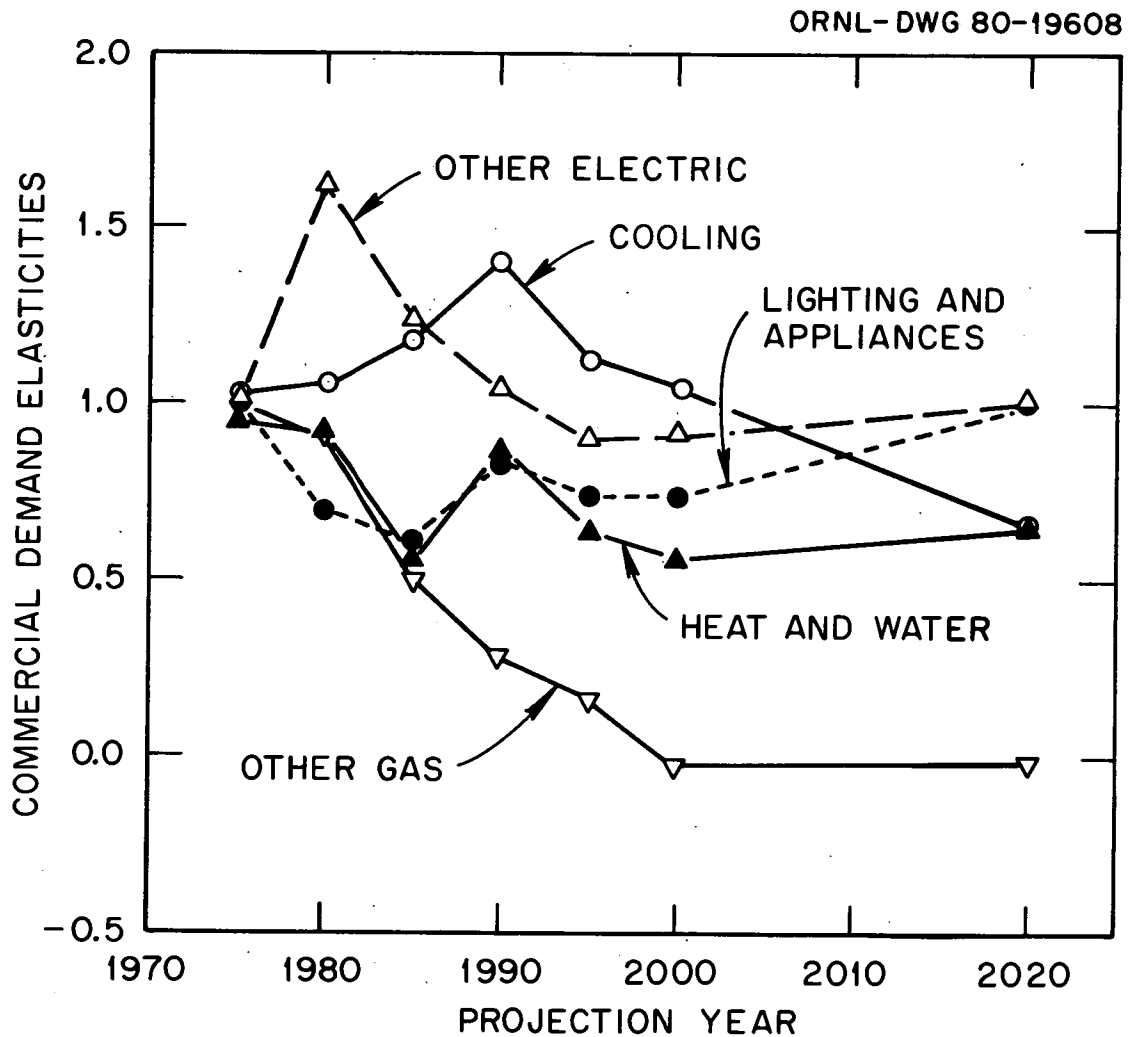


Fig. C.9. The Model 22C Demand Elasticities for the Commercial Sector

APPENDIX C-10

MODEL 22C DATA BASE FOR THE IMPORTS/EXPORTS SECTOR

This Sector is handled in a very simple manner as diagramed in Fig. A-5 of Ref. 4. Fixed import prices for each model year are placed on crude oil, oil products, and gas with no restraint on import quantities. These prices are compiled in Table C.10.a.

The only exports considered are fixed quantities for metallurgical coal (some non-metallurgical is also included here). Actually, the U.S. does export petroleum products, but the quantities are very small compared to imports. The metallurgical coal exports are tabulated in Table C.10.b.

It is important to note the extremely low fixed import prices on oil and oil products compared to 1980 prices, especially since oil import quantities decrease significantly over the time frame of the model even at these low prices using the Model 22C Input Data. The total demand for liquid fuels is, to first order, determined by the modeler; supply is always equal to demand; therefore, the total supply of liquid fuel is very sensitive to the demand elasticities. Perhaps the most important aspect in using the LEAP model is to predict the types of liquid fuels which are supplied in order to meet the input demanded. Liquid fuels are essentially non-substitutable except for the possible replacement of present gasoline vehicles with those powered by electricity, alcohol, or hydrogen in the Transportation Sector. Using the Model 22C input data, however, electrically powered automobiles did not penetrate the market significantly even in the year 2020.

That these import prices are low is well known; they have been described in a number of reports (i.e., Ref. 18) and, in particular, in the 1979 Annual Report to Congress,[19] therefore little additional information

need be appended here. It should be noted, however, that input errors found in the Transportation Sector (and elsewhere) when corrected, did allow penetration of the electric car upon analysis of this "revised" run.[a] More importantly, other parameters were found to be more sensitive than prices in determining the import quantities; see, for example, the discussion in Section III. G on FREQPR, the shares at equal prices for refined products in the Oil/Gas Sector.

[a]Further discussion can be found in Section VI.

Table C.10.a. Import Prices in $/MMBtu (1975$) for Crude Oil, Gas, and Oil Products in the Import/Export Sector

	Model Year							
Imports	1975	1980	1985	1990	1995	2000	2005	2020
Crude Oil	2.02	2.17	2.17	2.68	3.40	4.28	4.35	4.35
Gas	2.02	2.17	2.17	2.68	3.40	4.28	4.35	4.35
Oil Products	2.62	2.77	2.77	3.28	4.00	4.88	4.95	4.95

Source: LTEAD[6]

"The fixed price paths for this node were obtained from the MEFS Series C output."

Table C.10.b. Export Quantities in Quads/year for Metallurgical Coal in the Import/Export Sector

	Model Year									
Exports	1975	1980	1985	1990	1995	2000	2005	2010	2015	2020
Met. Coal	1.80	2.16	2.69	2.86	3.03	3.1	3.2	3.3	3.4	3.5

Source: LTEAD[6] assumption

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