

ENPEP: An Integrated Approach to Energy Planning

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ABSTRACT

Many models have been developed to analyze various aspects of the energy system. The Energy and Power Evaluation Program (ENPEP) is a set of microcomputer-based energy planning tools that are designed to provide an integrated analysis capability. ENPEP begins with a macroeconomic analysis, develops an energy demand forecast based on this analysis, carries out an integrated supply/demand analysis for the entire energy system, evaluates the electric system component of the energy system in detail, and determines the impacts of alternative configurations. This approach is an enhancement of existing techniques in that it places emphasis on looking at the electric system as an integral part of the entire energy supply system. Also, it explicitly considers the impacts the power system has on the rest of the energy system and on the economy as a whole.

INTRODUCTION

ENPEP was originally developed by Argonne National Laboratory under the sponsorship of the U.S. Department of Energy (DOE). ENPEP is designed as a user-friendly analysis package that can be employed by energy planning agencies in industrialized and developing countries. It is currently being distributed worldwide under the auspices of the International Atomic Energy Agency, the World Bank, as well as DOE. All or parts of the ENPEP system are in use in at least 50 countries. Numerous applications are under way.

This paper provides a brief description of the ENPEP system, its theoretical framework and its implementation as an integrated planning tool. The focus is on the models which address planning at the complete energy system level. The electric system planning models will be described in less detail.

OVERALL ENPEP STRUCTURE

ENPEP consists of nine technical modules that deal with various aspects of the energy system. Each module has automated connections to other ENPEP modules but also has stand alone capability. Figure 1 gives the overall structure of the ENPEP system. The technical modules of ENPEP and their primary function are:

Complete Energy System Level

MACRO	Allows the user to specify macroeconomic growth (global or sectoral) that will be the drivers of energy demand.
DEMAND	Projects energy demand based upon the macroeconomic growth information provided in MACRO.
BALANCE	Computes equilibrium energy supply/demand balances over the study period.
IMPACTS	Estimates environmental residuals and resource requirements for the energy system determined by BALANCE and/or ELECTRIC.

Detailed Electric System Planning

PLANTDATA	Provides a library of technical data on electric generating plants that is used in BALANCE and ELECTRIC.
MAED	Conducts a detailed analysis of energy and electricity demand and produces electric

MASTER

	load forecasts for use in ELECTRIC.
LDC	Computes detailed electric load forecast information for use in ELECTRIC.
ELECTRIC	The microcomputer version of WASP-III, calculates the minimum cost expansion plan for the electric generating system to meet electric demand and reliability goals.
ICARUS	Performs detailed production cost and reliability calculations for a specified electrical generating system.

MACRO MODULE

The macroeconomic analysis module is the starting point of the ENPEP system. It is designed to provide projections of the level and structure of economic growth in the country. These projections are used in subsequent modules to determine the energy demand (both fuel and electricity, or useful energy) resulting from economic growth and the size and structure of the energy supply system required to meet that demand. Because the macroeconomy and the energy system are interdependent, the macroeconomic analysis must also provide for feedback from the detailed energy analysis. This feedback will allow for a self-consistent set of energy and supply projections to be made, assuming that the energy supply can support the designated level of economic growth.

The macroeconomic analysis addresses all sectors of the economy including industry, agriculture, transportation, and services. The analysis deals with the factors affecting economic growth, and alternative economic growth scenarios are developed based on different sets of assumptions. The principal outputs of the analysis are forecasts of economic growth expressed in monetary units (GDP, value added) and disaggregated by economic sector (cement industry, textile, commercial services, ...). The analysis may include demographic projections (such as population growth, housing patterns, employment) as well as financial forecasts such as capital formation, and savings rate.

The macroeconomic analysis conducted in any country is dependent on the data available, the analytical tools employed, and the preferences of local economists. Among the more widely used techniques are trend extrapolation, time series analysis, input/output analysis, and econometric forecasting. It is not the intent of the ENPEP system to develop or recommend a single macroeconomic analysis approach. Rather, the objective is to provide a structured format into which macroeconomic projections can be put, independently of how they were derived. This approach requires the user to conduct the macroeconomic studies outside the ENPEP system and then to format the results for use by ENPEP. This technique accommodates the wide variety of macroeconomic approaches used in different countries. Thus, the decision was made to use MACRO as an interface rather than an actual planning model.

Each of the growth parameters entered into MACRO is given a unique identifying code. This allows the user to apply the growth in that parameter to some portion of the energy demand in the DEMAND module.

DEMAND MODULE

The energy demand forecasting module is tightly linked with the macroeconomic analysis module, from which it receives economic growth data, and with the integrated energy supply/demand module, to which it supplies demand forecasts in terms of end-use energy or fuel use projections. The objective of the energy demand module is to convert the economic forecast, expressed in economic or physical quantity terms into energy demand forecasts on as simple or disaggregated a basis as the ENPEP user may want.

One of the most frequently used methods of developing energy demand forecasts is to relate the current fuel and electricity consumption to the economic activity and apply the economic growth rates to the energy use. Since this a simple procedure and requires only the minimum amount of data, it is frequently used in making energy demand forecasts. The approach is appropriate for studies with limited time and resources and in countries where more detailed data are simply not available or desired.

For the ENPEP analyst who has access to more extensive energy use data and who desires to account for developments such as fuel-switching, technology improvements, and market influences, an alternative energy demand framework is provided. In this case, the economic forecasts are not translated into energy consumption

by economic sector but rather are converted into useful energy demand by end-use category. Useful energy is the actual energy used by the consumer to perform a useful function (eg. provide heat), and is the energy output of a conversion device. Useful energy differs from the energy consumption by the efficiency of the conversion device.

The output of the energy demand module is either a projection of fuel and electricity use or a projection of useful energy demand by economic sector. It is expected that the number of economic sectors in studies may be as few as three or four (e.g. residential, commercial, industrial, and transportation). However, the MACRO and DEMAND modules allow for 30 sectors each containing up to 30 subsectors.

BALANCE MODULE

The BALANCE module is designed to integrate energy supply and demand activities for the purpose of providing information necessary for decision making. The supply/demand balance approach ensures that the amounts of fuels supplied and demanded are equal and that the quantities of fuels consumed are consistent with the costs of production and the prices paid by consumers.

BALANCE uses a non-linear, equilibrium approach to determining the energy supply demand balance. In this formulation, an energy network is designed that traces the flow of energy from primary resource (e.g., crude oil, coal) through to final useful energy demand (e.g., residential hot water, industrial steam). Figure 2 gives the sectors included in a simple country energy network.

In a BALANCE analysis, energy demand is sensitive to the price of supply alternatives and supply price is sensitive to the quantity demanded. BALANCE seeks to find the intersection of the supply and demand curve. In its operation, BALANCE simultaneously finds the intersection for all energy supply forms and all energy uses that are included in the network. There are two major operations in BALANCE:

Definition of the Energy Network: BALANCE uses a set of submodels, called *nodes*, to represent different components of the energy system. The user connects these nodes by a set of *links*. The links convey two pieces of information from one node to another: price and quantity. All sectors of the energy supply and demand system are included in a BALANCE analysis. The user is free to define the sectors and the nodes and links that are in each sector to meet specific analysis needs. Figure 3 gives an example of how the residential sector could be defined.

Development of the Equilibrium Solution: Once the energy network, consisting of the nodes and their connecting links with their associated data, has been entered into BALANCE, the equilibrium solution for all the years of interest is computed. This process starts with a base year balance. The base (first) year of the analysis is computed by starting with the base year production from all of the resource nodes (depletable and renewable) and computing quantity and price through all of the intervening nodes up to the demand nodes. To compute the balance for the second year in the analysis, the equilibrium algorithm is applied. The process starts with the resource nodes at the bottom of the network. A first estimate is made as to the quantity of each resource that will be produced in the year under analysis. At this point, the estimate is strictly a guess based on incrementing the previous year's production rate. The production rate is used with the resource supply curves to determine the first guess of production cost for each resource. An "up-pass" is then conducted in which the prices are computed across all of the nodes of the network using the resource prices as a starting point. In the up-pass, the quantities across the nodes are not calculated, only the prices. When the up-pass is completed, every link on the network has a first estimate of prices for the analysis year. The next step is to conduct a "down-pass" in which quantities are computed across each node of the network. This calculation starts at the demand nodes at the top and proceeds downward. In the down-pass, the prices on each link are used at the decision nodes to compute market shares. These shares are passed further down as demands to the nodes below. Finally, at the bottom of the network, the total quantity of each resource that has been computed from the down-pass, is determined. In general, the resource quantities used in the first estimate at the start of the up-pass, do not match the resource quantities computed through the down-pass. A solution algorithm is employed to readjust the quantity estimate and another up-pass and down-pass sequence is started. When the resource quantity estimate and the down-pass resource quantities are within a specified tolerance level for all resources, the solution is said to have converged to an equilibrium for that year. BALANCE proceeds to step through the analysis year-by-year. The resulting solution is a set of prices and quantities on all of the links in the network for every year of the analysis period. Currently,

up to 75 years may be included.

The solution that BALANCE generates provides a consistent picture of energy flow through the network for the set of assumptions and conditions that the user has specified. The solution is in "equilibrium" because the feedback effects of demand and supply adjusting to price differences have been included in the analysis. The energy flows and prices developed in BALANCE can be passed to the IMPACTS module where the environmental impacts and resource requirements are evaluated.

IMPACTS MODULE

Once an energy system configuration has been designed, the environmental impacts and resource requirements of that configuration must be evaluated. Frequently, an energy system that is designed solely from the energy supply perspective cannot be implemented because of environmental constraints or resource limitations. The IMPACTS module is designed to estimate these effects. Facilities from both energy supply systems and energy consuming systems can be included in the IMPACTS analysis (see figure 4). For example, coal mines, power plants, refineries, and natural gas lines may be included as supply systems. Industrial boilers, residential space heaters, and automobiles may be included as demand facilities. IMPACTS will determine the impacts of all these types of facilities. IMPACTS carries out five major functions:

Develops facility build schedule As with other modules in ENPEP, the IMPACTS module may be run in conjunction with the other modules or in a stand-alone fashion. IMPACTS begins by loading in an energy system configuration that consists of a list of the energy facilities and their energy use for up to 75 years of the analysis period. These facilities and energy use may be drawn from a BALANCE case, an ELECTRIC case, or input directly by the user. With the energy input and output, IMPACTS determines the build schedule for each facility. For example, it may have been determined from a BALANCE analysis that refineries will need to process a given amount of crude oil over the planning period. Using the typical size of these facilities, IMPACTS will determine the refinery build schedule. The build schedule is used to compute impacts on a plant-by-plant basis, to allow for a geographical distribution of impacts, and to selectively apply regulatory control programs.

Assigns facilities to geographical regions Each of the IMPACTS facilities can be located geographically to give an analysis of the spatial distribution of impacts. Regions and subregions are defined by the user. The location of facilities or individual plants that make up the build schedule can be assigned to each region.

Selects impact coefficients from databases One of the biggest problems encountered in doing an impact analysis, particularly in developing countries, is the availability of a consistent set of data. IMPACTS addresses this issue by providing the user with two extensive databases that can be used directly or can be modified with local data. The databases are the Generic Energy Database (GED) and the Generic Facility Database (GFD).

The GED gives information on different forms of energy that can be used in the impact analysis. For each generic energy form, the GED gives a set of data that is needed to make the impact calculations. These data include physical, cost, and chemical content parameters. The parameters specified vary with the energy form.

The GFD gives data on typical energy facilities. The data include information on the following impacts:

- Air pollutants
- Water supply and pollutants
- Land use
- Solid waste
- Resource requirements (labor and materials)
- Occupational health and safety

For each impact, information is given for uncontrolled conditions (e.g., air pollutant emission, water pollutant emissions) and on available control techniques. Up to 10 control techniques are specified for each type of impact. The techniques may be in the form of add-on equipment (e.g., electrostatic precipitators, biological water treatment plants) or they may be operational procedures (e.g., the use of low excess air for nitrogen oxide air

pollutant control). The process of selecting which technique will be used will be discussed later.

The data in the GFD is specified in a form normalized to the size of the plant. For example, air pollutant emission factors are given in kg per GJ of energy input. This allows the information to be used when analyzing real facilities that are not exactly the same size as the generic facility. To allow for the limitations in scaling (e.g., scaling emissions from an 800 MW coal-fired power plant down to a 100 MW unit may not be appropriate), the GFD contains information on a range of facility sizes.

In using the GED and the GFD, the user simply identifies which generic energy and which generic facility are the closest to the actual facility under study. The model then copies all the necessary coefficients and scales them appropriately to the actual facility size.

Applies regulatory controls: For each of the impacts considered, regulations can be applied to reduce the environmental discharges or other effects. The type of regulation varies with the impact being evaluated. The regulations can be imposed singly or in combinations. It is possible to designate regulations that will apply only to certain facilities, types of facilities, in designated geographical areas, after a specified starting date, or to new, existing, or all facilities. This gives the user flexibility to apply different regulatory control programs.

Computes impacts: Once the coefficients from the GED and GFD have been selected and the regulatory control structure has been established, IMPACTS proceeds to compute each of the impacts both with and without controls. This calculation is repeated for all pollutants for all years of the analysis. It is also repeated for all facilities included in the study. The uncontrolled emission calculation is one of the basic outputs of IMPACTS. The next step is to apply the regulatory controls that have been specified. IMPACTS first considers which of the regulations apply to the facility under study. The regulation's facility application, regional application, start year, and applicability to new or existing sources is checked. If the regulation does apply to the facility, then an appropriate control device, from the list of those available for use on this facility, is selected. There are a series of decision rules that determine how devices will be selected for both new and existing facilities. The basic principle is that the lowest cost device that meets the regulation is selected, where cost is calculated with consideration of both capital and operating costs. The decision rules allow for situations where different equipment must be used to control different pollutants (e.g., electrostatic precipitators for particulate control and scrubbers for sulfur oxide control) and for situations where the user has specified a regulatory program that cannot be met with any of the available devices. Once the control device is selected, IMPACTS recomputes the impacts, this time accounting for the effectiveness of the control equipment. Again the calculation is carried out for all pollutants, for all years, for all facilities. Calculations for all of the other impact parameters are done in an analogous fashion.

In dealing with the impacts in this fashion, IMPACTS is said to address the "residuals" of the energy system. IMPACTS does not delve into the next steps of a complete environmental assessment by doing calculations of pollutant transport, population exposure, or risk assessment. These are better left to other models at this time.

PLANTDATA MODULE

The PLANTDATA module serves as a library of basic information about thermal and hydroelectric generating facilities for both the BALANCE and ELECTRIC modules. Since these two modules require similar information about the electric generating sector, PLANTDATA is intended to provide a consistent set of electric generating system data, while eliminating redundant data entry. The entire set of thermal plant and hydroelectric plant descriptions may be printed in the form of an output data book.

MAED MODULE

The Model for Analysis of Energy Demand (MAED) is a simulation model designed to evaluate medium and long-term demand for energy in a country (or region). MAED was developed by the International Atomic Energy Agency and was originally based on work done at the University of Grenoble in France.

MAED offers an alternative approach to MACRO-DEMAND-BALANCE-LDC for estimating energy and electricity demands. It is based on a detailed breakdown of the final energy demand of the country into a

multitude of categories of end use by consumer sector (cooking in households, heat in manufacturing industry, motor fuels for transport of passengers). The growth of the demand for each category is related to the evolution of one or more socioeconomic (population, GDP), technical (efficiencies of end use equipment) and policy (preferences of one fuel over the others) parameters that are known to affect this category of end use.

MAED has additional submodules to permit a more detailed treatment of electricity demand and to convert the annual results (GWh) into the hour-by-hour electricity requirements (MW) and finally rearrange these hourly demands into load duration curves in the format required as input by the ELECTRIC module.

LDC MODULE

The LDC module was developed under the sponsorship of the Hungarian Electricity Board. The objective of the electric load forecasting module is to further elaborate on the information provided by the MAED and BALANCE modules in order to provide the complete set of load and energy forecast needed by the ELECTRIC and ICARUS modules. The expected input to LDC is a projection of total electricity demand for the entire planning horizon. The output of the electric load forecasting module is a forecast of the seasonal generation to be supplied and the seasonal peak loads to be met by the generation system.

LDC was designed with a variety of users in mind. The major objective was to provide a convenient way to prepare load data for ELECTRIC and to assist users who have limited data and means to make projections. Of special concern were users who do not have a basis for projecting the shapes of future load duration curves but who have a basis for expecting period load factors to change over the years. On the other hand, it was considered important to accommodate advanced users who are able to project these curves outside ENPEP. Therefore, options are provided to estimate load duration curves having specified load factors for users with only historical load duration curves or no other period load factors. For advanced users, an option is provided to directly specify the load duration curves over time.

ELECTRIC MODULE

The large number of alternative technologies with varying economic and operational characteristics is just one of the factors that have made decision making on capacity expansion increasingly more complicated. Longer construction periods, uncertain load growth, cost and availability of fuels, and expensive pollution control equipment must also be taken into consideration when a planner is deciding the number, type, and size of generating units to be installed.

The objective of the ELECTRIC module is to determine the generating system expansion plan that adequately meets demand for electric power at minimum cost while respecting user-specified constraints. ELECTRIC is directed to long-term planning beyond a 10 year time horizon and is intended to address a number of critical issues in generation planning, including generating unit size, system reliability, details of the existing system, seasonal variation in loads and hydroelectric availability, and appropriate simulation of future system operation.

ELECTRIC is the microcomputer version of the Wien Automatic System Planning Package (WASP-III), which is the well-known mainframe electric system planning model distributed by the International Atomic Energy Agency. ELECTRIC is a comprehensive simulation package for conducting long-term system expansion studies. Its focus is on selecting optimal mixes of technology alternatives to meet demand growth and to provide replacement capacity for unit retirements. It is important to use a comprehensive model, like ELECTRIC, to address the dynamic issues and parameters associated with long-term utility planning. The expansion options that appear most attractive in terms of isolated technology costs do not necessarily provide the least-cost expansion option when examined in the context of integrated system operations. In addition to the costs considerations, unit sizes, operating availabilities, and existing system configurations are instrumental in determining optimal expansion strategies.

ELECTRIC explicitly recognizes the probabilistic aspects of production-cost and system-reliability analyses as well as other key parameters such as unit-size effects, fixed-cost versus variable-cost tradeoffs, nondispatchable technologies, and study-period end effects. ELECTRIC uses probabilistic simulation to estimate generating system production costs and dynamic programming to determine the optimal expansion pathway.

Reliability of the electric generating system is measured in terms of reserve margin, loss-of-load probability, and expected unserved energy. Unserved energy is the demand that is not met because of capacity or energy shortages that result from random forced outages, scheduled maintenance, or lack of hydroelectric energy.

A primary motivation for ENPEP's development is that evaluations of alternatives for expansion of electrical generating systems should not be conducted in isolation with respect to important related considerations, such as overall economic growth, demand for all forms of energy, supply of alternative energy forms, relative cost of energy forms, and environmental impacts of alternative supply systems. For this reason, ELECTRIC is integrated with the PLANTDATA, BALANCE, LDC, MAED, ICARUS, and IMPACTS modules of ENPEP. Although these components of ENPEP are fully integrated, the ELECTRIC module can be used as a stand-alone system.

ICARUS MODULE

The module for Investigating Costs and Reliability in Utility Systems (ICARUS) performs a detailed unit level operation of the electric generating system. It is an extension of the simulation algorithm of ELECTRIC (WASP-III) and removes some of the approximations that were needed to be introduced in ELECTRIC as a trade-off between level of detail and running time. For example, ELECTRIC allows a maximum of 60 unique plants and a maximum of 12 periods per year, whereas ICARUS can carry out production costing and system reliability calculations considering up to 600 unique plants and time periods of one week to one year.

The combination of ELECTRIC and ICARUS used in tandem allows the energy planner to perform Long-Range Marginal Cost (LRMC) calculations for the electric power system for different years and system configurations. This LRMC can serve as the basis for setting the structure of electricity tariffs if so required.

ENPEP APPLICATIONS

ENPEP was designed for distribution to countries with a need for energy planning analysis tools. Distribution of the package is handled by the U.S. Department of Energy. Under an agreement with the International Atomic Energy Agency, ENPEP is also distributed to member countries of the International Atomic Energy Agency (IAEA) as part of technical cooperation projects. There is no charge for ENPEP. To date, all or part of ENPEP has been distributed for use in more than 50 countries.

The IAEA and World Bank, in cooperation with DOE, have conducted several training courses on the use of ENPEP. Participants, in teams of two or three from a country, receive up to nine weeks of training in the use of the ENPEP modules. Since 1978, over 400 experts from 59 countries have received ENPEP training at Argonne. Additional courses are continually planned.

In addition to the developing country applications, ENPEP is currently being used for European energy system studies at the Commission of the European Communities (CEC), and for several energy policy studies in the U.S..

CONCLUSIONS

One of the intents in the development of ENPEP was to maintain a continuing update of the model. A number of enhancements are in process and more are planned. Capabilities are being added to several of the modules. Graphical interfaces and output displays are being developed. Testing is an on-going process.

ENPEP is being used in over 50 developing countries, at international organizations such as the CEC, World Bank, and IAEA, as well as, for U.S. applications at Argonne. The ENPEP system is clearly a state-of-the-art energy planning tool. Ongoing development efforts will assure that ENPEP evolves as the state-of-the-art in energy modeling evolves.

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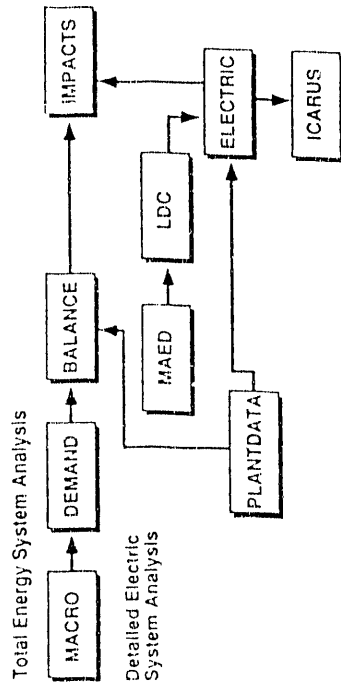


Fig.1 Enpep Structure

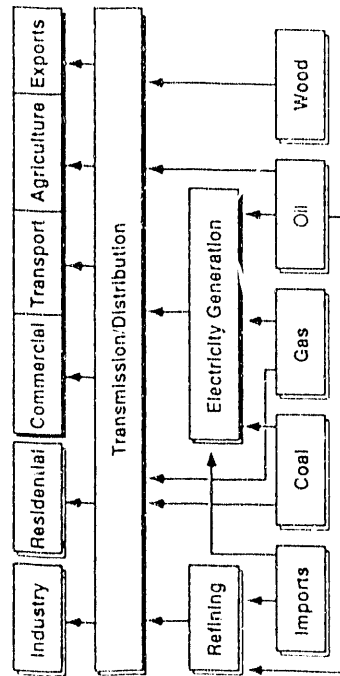


Fig.2 Simple Country Energy Sector Diagram

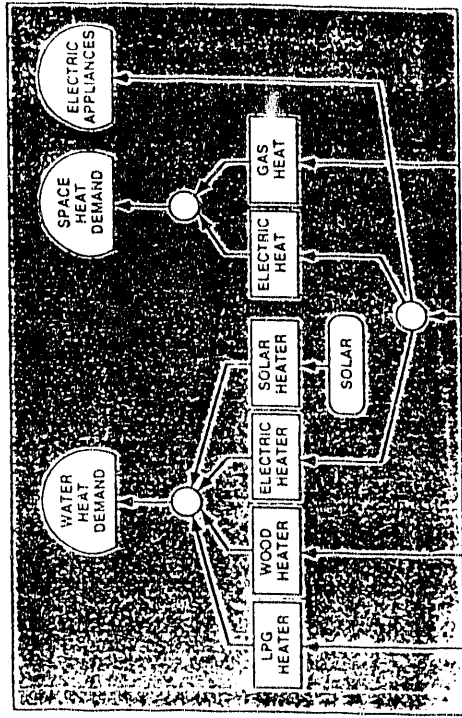


Fig.3 Example Network for Residential Demand

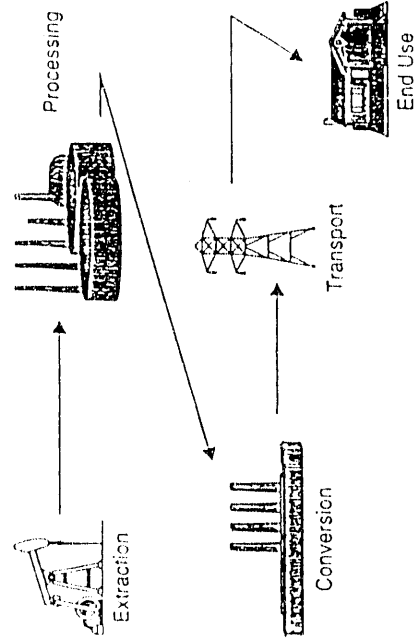


Fig.4 The Impacts Analysis is Fuel Cycle Comprehensive

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