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THE EFFECTS OF ALTERNATIVE OIL STOCKPILING PROGRAMS ON THE U.S. ECONOMY, 1976 - 1979 FINAL RESULTS

RAYMOND G. TESSMER, JR., AND DAVID J. BEHLING, JR.

June 1976

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Abstract

Application of Brookhaven's Energy Input-Output Model is demonstrated by analyzing economy-wide effects of an Oil Stockpile Program. The model is used to estimate the 1976-79 inter-industry output, employment, capital, and energy substitution effects of 730 and 4380 million barrel stockpiles. Two policy variables - the type of stockpile facility and the method of financing - and one assumption - balance of payments effects - are examined.

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I. Introduction

The subject of this report is the demonstration of a combined input-output, linear programming model. As will be shown, this model formulation provides a flexible framework for assembling and organizing a mass of factual data needed to describe the inter-workings of the U. S. economy. Data derived from many different sources - technical engineering studies, econometric time-series and cross-section estimates, and sample and census surveys - are incorporated into a unified analytical framework. The usefulness of this framework in identifying and clarifying public policy issues is demonstrated through an analysis of the effects of alternative oil stockpiling programs on various aspects of the U. S. economy. In particular, the combined model is used to estimate the 1976-1979 inter-industry output, employment, capital, and energy substitution effects of several alternative oil stockpile programs including the "high" and "low" stockpiles proposed by the MIT Energy Laboratory*(13). Besides stockpile size, the effects of several other related policy options are also analyzed, including type of stockpile capacity provided, methods of financing, and balance of payments adjustment mechanism.

The discussion will proceed in four sections.

1. The general problem of how best to minimize the risk of dependence on oil imports is presented with particular reference to the role oil stockpile programs might play in lowering this risk. Several alternative stockpile programs are defined with respect to their size, type of stockpiling facility, product-mix composition, timing and financing characteristics.

2. A general description of the combined IO-LP iterative model is given. This model relates given final demand forecasts to inter-industry output, employment and least-cost energy flow allocations. Major assumptions are also presented.

3. Estimates of alternative final demand forecasts associated with each of the alternative stockpile programs are developed and compared with each other and with a reference no-stockpile final demand forecast. The final demand estimates are what drive the model.

4. Estimates of the inter-industry output, labor, capital, and energy effects arising from each stockpiling program are presented.

The usefulness of the combined model in this and other

*They propose a stockpile of between 730 and 4380 million barrels of oil.

possible policy analyses is considered. A formal description of the mathematical combined model is presented in an appendix.

II. Statement of the Problem

1. Reasons for Government Encouragement of an Emergency Oil Stockpile Program

The development of emergency standby petroleum supplies by the federal government has been advocated as part of an overall strategy to cope with sudden interruptions in oil imports. Among those proposing a wide variety of stockpile programs are the Massachusetts Institute of Technology (MIT) Energy Laboratory (13), the National Petroleum Council or NPC (14), and the Federal Energy Administration (FEA) in its Project Independence Report (8).

While it can be argued that expectations of future oil import cutoffs will lead private profit-maximizers to store oil, the amount that would be stockpiled is very uncertain. There are also several factors that would discourage adequate stockpiling entirely through private market mechanisms. If, for example, reimposition of government price controls to discourage price "profiteering" in a shortage situation was anticipated, the private incentive to stockpile would be reduced. Also, the electric utilities which burn large amounts of residual fuel oil could have difficulty in obtaining authorization to include stockpiles in their rate bases. On a more pragmatic level, inadequate privately held stockpile capacity in the 1973-74 oil embargo period has led to legislation prescribing a federally administered stockpile, not to legislation that would prevent reimposition of allocation measures and price controls in another shortage condition.

The actual optimum stockpile program depends on many inter-related variables. In the long run, the most important variable is obviously the projected amount of oil imports, since the chief purpose of emergency stockpiles is to hedge against the risk of oil import disruption. The greater the amount we import, cet. par., the greater the expected damage from import disruption. The MIT study (13) makes the following long run case for stockpiles. The cost of stockpiling is largely a one-shot cost. However, the cost differentials between domestic and imported foreign energy sources will remain large and may grow, and these cost differentials will remain year after year. Hence, the fairly large one-shot cost involved in stockpiling oil is preferable to continuing real costs involved in developing high cost domestic substitutes for imported oil.

Until recently, most analysts, including the FEA (8), tied the level of desired oil stockpiles to the expected level of "unsafe" imports. However, Canada's recent announcements of concern over her own "energy independence" and the Venezuelan government's staunch support of OPEC have decreased the reliability

of these sources which were previously considered "safe". The future of our relations with practically all oil importers is obviously uncertain.

A variety of measures can be taken to minimize the oil shortfall in any future embargo. Some thought should be given to mechanisms which would encourage short-run coal for oil fuel substitution possibilities. Also, permitting price increases during an oil shortage emergency would reduce demand-an approach taken by many other countries during the 1973-74 embargo.

Contingency fuel allocation or rationing plans may also help minimize the impact of another embargo. A well-conceived and carried out rationing scheme would channel fuel from lower priority uses to higher priority requirements, saving jobs and production at the expense of personal convenience. The "learning experience" of the FEA during the last embargo should be helpful. However, as mentioned above, the anticipation of rationing or allocation plans which lower fuel prices from market clearing levels will lessen the incentive for private oil stockpiling and for other risk hedging behavior. Any commitment to stand-by oil allocation schemes should be accompanied by counter measures to encourage risk hedging. Stockpiling is the most frequently discussed type of risk hedging action considered. The purpose of this study is to identify and estimate the economy-wide costs of alternative stockpile programs.

Stockpile programs can be defined with respect to each of the following characteristics:

- .Type of Stockpiling Facility
- .Amount of Oil Stockpiled
- .Mix of Crude and/or Products Stockpiled
- .Sources of Crudes and/or Products to be Stockpiled
- .Timing
- .Financing
- .Balance of Payments

Each of these characteristics is considered in turn.

2. Types of Stockpiling Facilities.

Although oil can be stored in a variety of facilities, NPC, FEA, and most academic researchers agree there are five options: (1) shut-in oil wells; (2) conventional steel tanks; (3) on-shore salt domes; (4) off-shore salt domes; (5) off-shore nuclear-created rock caverns.

Shut-in oil wells - After oil is discovered, the well can be capped and saved for future use. The obvious advantage of this type of storage is that no direct storage charges are incurred. However, the disadvantages, compared with other alternatives, are greater. It takes up to two years to get production up to 100% MER (maximum efficiency rate) and then it takes another 5-15 years to fully exploit the reservoir. Hence only a very small

fraction of the total proven reserve is available for emergency use. Due to these time-lag problems and the current shortage of domestic oil, the creation of greater amounts of shut-in capacity is not recommended.

However, existing shut-in capacity is a potential source of oil for deposit in more convenient types of stockpile facilities or for sale as a replacement for oil imports. At present, the only significant number of shut-in wells potentially available as standby-oil reserves are the Elk Hills deposits, jointly controlled by the Navy and Standard Oil of California. Estimates of the 100% MER flow which would be available from Elk Hills after two years vary from 240,000 to 300,000 barrels per day.

Steel tanks - Steel tanks can be located almost anywhere - near ports of destinations, trans-shipment ports, or refineries. The rate of oil retrieval from steel tanks is rapid. Also, the amount of crude eventually retrieved is almost equal to the amount initially deposited as evaporation and other losses are negligible. These advantages are offset by one major disadvantage, the cost, as steel tanks are more expensive than all potential alternatives. Costs vary significantly with location, due to variation in land acquisition, transportation and labor costs. Recent cost estimates vary from \$3 to \$7 per barrel of capacity. An average cost of \$4.50 per barrel (1974 dollars) was used in this study.

On-shore salt-dome storage - The National Petroleum Council (14) estimates that storage in salt domes can be provided for \$0.60 to \$0.85 per barrel if the volume to be stored exceeds 100 million barrels, while an MIT study (13) cites an estimate of \$1.00 per barrel. A large capacity is required both to minimize losses due to inability to eventually recover all the oil deposited and to maximize the rate of the redelivery flow. The NPC estimates a "several million barrel per day" redelivery rate for a 200 million barrel deposit. Conservatively translating "several" into four, all recoverable oil could be redelivered in 50 days. Many sufficiently large salt domes are located both on and off-shore in the Gulf Coast area. Since these domes are located 2,000 or more feet below the surface, they are more secure against disasters and sabotage than steel tank storage.

Two techniques are available for mining the salt domes to create cavities - hot water leaching and nuclear explosives. For hot water leaching, on-shore salt domes located near the Gulf could be used. Many wells are drilled into the salt (NPC estimates 20 to 40 wells per 200 million barrel deposit), hot water is then pumped into the wells to liquefy the salt, and then the salt water brine is pumped out into the Gulf and oil is pumped into the leached cavity. Drilling costs are much less for on-shore than off-shore projects, while pumping and brine disposal costs are minimized by close access to the Gulf. However, potential on-

shore sites may have high land acquisition costs, for the surface of these sites tends to be elevated and so are likely to be built upon. Also, sub-surface mining rights are often owned by independent oil companies.

Off-shore salt dome storage - Off-shore salt dome storage cavities could be created by peaceful nuclear explosions (PNE). Actual experience with nuclear explosive gas stimulation projects in Colorado has indicated that radioactive air or ground-water releases would be practically nil. Thus it is expected that radioactivity effects from the stockpiled oil would be minimal (6), (10), (12), and (16). Use of PNE would alleviate much of the drilling and pumping activity required with use of hot water. However, after PNE and before insertion of oil in the cavity, pumping installations would be required to pump water in and out of the cavity to wash out any remaining radioactive elements.

Costs per barrel of capacity tend to decrease as the size of nuclear charge and the resulting size of cavity increase. However, larger cavities can only be created farther out from land due to seismic after shocks on the land structures, and the farther the distance from land, the greater the accompanying pipeline costs. The net result of these offsetting effects is that the aggregate cost per barrel of capacity from PNE remains constant over a wide range of distance and capacity size configurations (7).

Off-shore PNE-created rock cavities - American and French studies have considered the feasibility of off-shore storage systems created by PNE in rock rather than salt formations (18) and (7). Unlike salt cavities, PNE created rock cavities could be located most anywhere. Likely locations would be on the East Coast near refineries and electric utilities, or in the Caribbean, near Puerto Rican and Virgin Island refineries, which normally import oil for refining into residual fuel oil for shipment to East Coast electric utilities. Cost estimates for PNE created rock cavities run higher than those for salt, since a given size nuclear blast creates a larger sized cavity in salt than rock. In addition, greater total oil recovery rates are possible from salt cavities than from rock cavities.

In the analysis to follow, four types of stockpiling capacity are distinguished: steel tanks (steel); on-shore leached salt dome cavities (leached salt); off-shore nuclear-created salt dome cavities (nuclear salt); and off-shore nuclear-created rock cavities (nuclear rock).

Cost estimates of these activities, on a barrel of input capacity basis by type of industry purchase, are listed in Table 1. These costs are in terms of late 1974 prices. In general, the aggregate cost estimates were obtained by taking mean values

TABLE 1
Inter-Industry Cost Estimates
for Alternative Stockpile Capacities

	Steel \$4.50/barrel		Leached Salt \$1.00/barrel		Nuclear Salt \$.90/barrel		Nuclear Rock \$1.50/barrel	
	<u>\$/barrel</u>	<u>% of total</u>	<u>\$/barrel</u>	<u>% of total</u>	<u>\$/barrel</u>	<u>% of total</u>	<u>\$/barrel</u>	<u>% of total</u>
Motive power			\$.004	.4	\$.003	.3	\$.005	.3
Misc. thermal including drilling	\$.018	.4	.025	2.5	.016	1.8	.026	1.8
Water heat			.001	.1	.001	.1	.002	.1
Space heat	.009	.2	.003	.3	.002	.2	.003	.2
Air Conditioning	.005	.1	.001	.1	.001	.1	.002	.1
Electric power	.013	.3	.006	.6	.004	.5	.007	.5
New construction	.900	20.0	.200	20.0	.225	25.0	.375	25.0
Wood products	.225	5.0						
Chemical including nuclear					.180	20.0	.300	20.0
Stone, clay products incl. cement	.360	8.0						
Fabricated structural steel	2.025	45.0	.020	2.0	.018	2.0	.030	2.0
Pipe, valves, fittings			.060	6.0	.081	9.0	.135	9.0
Engines and turbines			.040	4.0	.027	3.0	.045	3.0
Construction and mining equip.			.080	8.0	.036	4.0	.060	4.0
General indust. equip. incl. pumps	.090	2.0	.300	30.0	.180	20.0	.300	20.0
Scientific instruments					.009	1.0	.015	1.0
Railroads	.180	4.0	.010	1.0	.009	1.0	.015	1.0
Trucking	.225	5.0	.020	2.0	.018	2.0	.030	2.0
Water transportation	.045	1.0	.070	7.0	.036	4.0	.060	4.0
Pipeline transportation			.020	2.0	.018	2.0	.030	2.0
Trade	.045	1.0	.020	2.0	.018	2.0	.030	2.0
Real estate	.270	6.0	.100	10.0				
Business travel	.045	1.0	.010	1.0	.009	1.0	.015	1.0
Office supplies	.045	1.0	.010	1.0	.009	1.0	.015	1.0
TOTAL	\$4.50	100.0	\$1.00	100.0	\$.90	100.0	\$1.50	100.0

of all the different estimates obtained. The inter-industry break down of these costs is very rough. Most were estimated on the basis of the informed judgement of BNL technical personnel.

For steel tanks a Bachtel source (3) was used to estimate the inter-industry break down. The major material purchases are fabricated steel for the tanks and concrete and wood for foundations. Costs of transporting these material inputs to the tank sites are charged to trucks, railroads, and water in that order of importance. Little energy is required directly for construction. The actual concrete and wood foundation costs, and the real estate purchase costs, will depend greatly on the actual location of the tanks.

It was assumed that the inter-industry percentage cost break-down for nuclear salt would be the same as that for nuclear rock. The percentage estimates for pipeline and pumps, and chemical (nuclear) costs are based on (7, p.3). It was also assumed that drilling and pumping activities for nuclear operations would involve greater direct energy expenditures than those for steel. Transportation and port activity requirements for off-shore storage would also be more water-oriented than for steel tanks.

For leaching, it was assumed that pumping, drilling, and direct energy requirements would be greater than those for nuclear activities and that water transportation requirements to get the crude inland would be greater. As previously mentioned, real estate costs would also be higher for inland salt storage than for off-shore storage.

3. Amount of Oil Stockpiled.

The MIT study (13) recommendations of 4,380 million and 730 million barrels of output capacity are both considered. At the commonly projected import level of 8 to 10 million barrels per day for the U.S. in the late 1970's, the high stockpile amount would allow for a total import boycott of at least a year and one half, assuming minimal amounts of other allocation and emergency conservation measures, while the low stockpile would provide only 3 months protection. Under the second strategy, greater reliance would have to be placed on other emergency measures.

To provide for a given output capacity, more oil would have to be provided for underground than tank storage, since some oil deposited in the salt domes could not be redelivered. A 95% redelivery rate was assumed for all underground storage, so that 1.053 barrels of input are required per barrel of output for salt domes and rock storage.

4. Mix of Crude and/or Products Stockpiled.

In general, crude oil storage is preferred to storage of refined products, as the versatility of modern refining tech-

niques allows for the correction of any crude quality deterioration which might occur during storage. Storage of crude also allows for the production of a variety of end product mixes. This quality and product-mix flexibility option gained via refining does not exist if products rather than crude are stored.

However, residual fuel oil may be an exception. Recently residual has accounted for one third to one half of all U.S. crude oil and oil product imports, and most of this goes to East Coast electric utilities. Given continued East Coast electric utility dependence on imported residual fuel oil, two alternative risk-prevention measures are possible. One is to use Gulf Coast-stored crude to produce residual fuel oil in U.S. refineries and transport the residual fuel oil to the East Coast via pipeline and/or ship. The other is to store residual fuel oil near the East Coast users.

Several bottlenecks might arise with total reliance on Gulf Coast storage of crude. First there may be a lack of refinery capacity to refine the crude. This likelihood becomes greater if the amount of imports of refined products continues to increase. OPEC has recently signified its intent to increase its refinery operations. Also, even if U.S. refineries are used to refine the crude into residual, considerable changes in refinery processes would be required for most mainland U.S. refineries. Currently most U.S. residual-oriented refineries are located in the Virgin Islands and Puerto Rico. Finally, large-scale shipping of crude and/or refined from the Gulf Coast to the East Coast during an embargo might necessitate reliance on foreign ships and repeal of the Jones Act.

For all of these reasons, storage of residual fuel oil via conventional steel tanks on the East Coast was explicitly considered as one potential option.

5. Sources of Crude and/or Products to be Stockpiled.

In the near future there are two sources: more imports and/or the Elk Hills shut-in capacity. It has recently been proposed by the Administration that Elk Hills oil be immediately tapped, and initially be sold on the free market, displacing imports in the process. Then, when stockpile facilities are in place, the Elk Hills oil could be placed in the stockpiles together with an amount of imported oil equal to the amount of imports previously displaced by the open-market sales. Given the expected range of Elk Hills annual production estimates, it would take from 7 to 10 years to achieve the MIT low stockpile amount of 2 million barrels per day for one year.

Thus for any sizable and rapid oil stockpile plan, imports will have to be purchased. Currently, the price and availability of oil, and the degree to which increased oil stockpile

purchases will increase the price of oil are all uncertain. In the analysis to follow it is assumed that the market price of oil will remain at \$10 per barrel and the price of residual fuel oil at \$9.50 per barrel until at least 1980, while the average price of all other U.S. exports and imports will increase 8% during 1975, 6% during 1976, and 4% per year from 1977 on. These price assumptions are midway between those implied by OPEC's stated desire to tie the nominal price of oil to a price index, and by the current decline in the price of oil and the increased inventories, both of which trends have been brought on by the recent world-wide recession.

Two alternative assumptions were made concerning the possible change in price brought on by increased oil import purchases: first that OPEC will act as a price taker, keeping the supply of oil perfectly elastic at \$10.75 per barrel; and second, that the price elasticity of OPEC oil supply will equal 1.0.

6. Timing

For all alternative stockpile plans analyzed, it was assumed that actual stockpile construction activity would take place at an even rate over a four year period, starting January 1, 1976 and that all oil would be purchased over a two year period, starting January 1, 1978, thus allowing a two year lead for completion of initial stockpile facilities.

7. Financing

Two different mechanisms for financing construction and oil purchases are considered:

- 1) raising general taxes (personal income and corporate income;
- 2) raising the federal excise tax on gasoline.

Two other possible financing mechanisms not examined are:

- 3) placing a federal excise tax on crude;
- 4) selling government bonds (deficit financing).

8. Balance of Payments

It is assumed that foreigners can do three things with the increase in dollars they receive for the oil that is stockpiled. They can buy goods and services from U.S. firms, increasing direct exports; they can buy U.S. financial assets (e.g. stocks and bonds) or buy real assets (e.g. land, buildings, factories), all of which would comprise transfers in U.S. assets; or they can spend the dollars to obtain other types of currencies. The latter would decrease the value of the dollar relative to other currencies, and this dollar devaluation, in turn, would lead to more U.S. exports and less U.S. imports, or an increase in net exports.

In order to examine a range of possible actions by foreigners, three balance of payments assumptions are analyzed. The first, "Dump", assumes that 100% of the payments to foreigners for the stockpiled oil are dumped on the foreign exchange market, resulting in dollar devaluation and an increase in net exports. The second, "Balanced", assumes that 50% of the payments are spent on the foreign exchange market, 25% are spent directly on U.S. exports, and 25% are used to purchase U.S. assets. The third, "Recycle", assumes that 50% of the payments are spent directly on U.S. exports, and 50% are used to purchase U.S. assets.

9. Summary of Stockpile Variables to be Analyzed.

- . Types of capacity:
 - Steel
 - Salt-leaching each constructed over a
 - Salt-nuclear 4-year period, 1976-9.
 - Nuclear rock
- . Size (output capacity):
 - 730 million barrels
 - 4380 million barrels
- . Products:
 - Crude oil
 - 25% Residual fuel oil/75% crude oil
- . Sources of crude or residual:
 - Imported (purchased over a 2-year period, 1978-9)
- . Financing:
 - Income tax
 - Gasoline tax
- . Price Elasticity:
 - No price elasticity
 - Crude oil supply elasticity of 1.0
 - Gasoline demand elasticity of 0.1
- . Balance of Payments
 - Dump
 - Balanced
 - Recycle

III. Description of Model and Data

1. Methodology

In order to analyze selected combinations of the above variables a base case was prepared. Output, employment levels, capital requirements, and cost minimizing energy allocations were estimated for 110 different industrial sectors for the years 1976-7, and 1978-9 on the assumption that no stockpile program was carried out. These are referred to as the base case results.

Then the same output, employment, capital and energy requirements were estimated under the assumption that a particular stockpile program was carried out. Any one of the possible combinations of the various assumptions is referred to as a delta run, and each is composed of a 1976-77 and a 1978-79 model solution. This procedure was then repeated for the nine delta runs listed in Table 2.

The two level, iterative model used for estimating the capital, labor, output, and energy requirements for the 110 industries is described in detail in the appendix. The entire model encompasses four different groups of relations: (1) an Input-Output (I-O) model for the entire economy, (2) a Linear Programming (LP) model for the energy sector, (3) inter-face equations between I-O model outputs and LP model inputs, and (4) interface equations between LP model outputs and I-O model inputs. The two sets of interface equations are required chiefly because of different levels of industry and product aggregation employed in the I-O and LP sub-models.

2. Input-Output Model

For the I-O model, the exogenous inputs are a vector of final demand (Y), a matrix of input-output coefficients (A) (excluding the various energy into energy coefficients which are endogenous to the entire combined model), and vectors of labor and capital coefficients. The A coefficients are projected 1985 coefficients from the Bureau of Labor Statistics, which have been aligned to BNL's 110-order industry classification. The BLS coefficients were changed from a 1963 dollar basis to a 1967 dollar basis using BLS supplied price inflators. It was assumed that all the non-energy coefficients will remain constant between 1976-7 and 1978-9, for the different stockpiling scenarios.

The 1967 labor coefficients supplied by the Center for Advanced Computation (CAC) (11) are defined in terms of man-years per 1967 dollars worth of output. They were used to indicate changes in labor requirements resulting from different sectoral production patterns. The 1975 capital coefficients obtained from Battelle (9) are also measured in terms of 1967 dollars worth of capital per dollar of output.

Base case final demand was estimated for 1976-7 and for 1978-9 by taking the averages of several of the most recent GNP estimates for these years. These estimates were obtained from a wide variety of sources. The GNP estimates for 1976-7 and 1978-9 are then adjusted to a final demand basis consistent with the 110-

Table 2

Cases Analyzed

	Stockpile Size	Type of Capacity	Product Stored	Financing	Price Elasticity	Balance of Payments
Base	none	—	—	—	—	—
1	small	S	crude	IT	—	D
2	small	LS	crude	IT	—	D
3	small	NS	crude	IT	—	D
4	small	NR	crude	IT	—	D
5	large	C	crude & ref	IT	ϵ_s	D
6	large	C	crude & ref	GT	ϵ_d	
7	large	C	crude & ref	IT	—	D
8	large	C	crude & ref	IT	—	B
9	large	C	crude & ref	IT	—	R

Legend: S-steel, LS-leached salt, NS-nuclear salt, NR-nuclear rock, C-combination.

IT-income tax, GT-gas tax.

ϵ_s -supply elasticity = 1.0, ϵ_d -gasoline demand elasticity = 0.1.

D-dump, B-balanced, R-recycle.

order industry classification system used in the study. Value added components of government, household, and the rest of world purchases were deleted. These deletions chiefly involve the wage incomes of government employees and transactions of U.S. firms located overseas. Inter-industry break downs of each component of final demand (consumption, fixed investment, inventory change, government, exports and competitive imports) are taken from a previous BNL study (4). This study documents both 1985 final demand estimates and these 1976-9 final demand estimates.

For each delta run, an analysis was made of how the final demands would change as a result of the particular stockpile program being analyzed. Then the revised final demand parameters were inserted in the I-O submodel. The relations between the stockpile variables and the final demands will be discussed in a following section.

3. Linear Programming Model

At present, BNL has estimated 1969 and 1985 values for all the parameters of the LP model (15). However, some of these parameters were revised to achieve definitional consistency between the IO and LP models. BNL estimates for energy prices were used, and the efficiency coefficients were assumed to be invariant with respect to changes in final demand. Energy supply schedules were assumed to be perfectly elastic except for Case 5.

The cost coefficients of the objective function of the LP model were assumed to remain at 1974 values (in terms of relative costs). However, in scenarios where the cost of crude increased on account of foreign supply, the costs of crude and refined oil product flows in the objective function of the LP model were increased relative to the price of other energy flows.

IV. Changes in Composition of Final Demand Due to Stockpile Programs

For every stockpile program analyzed, two runs are made, one for 1976-7 in which only stockpile capacity construction and associated financing activities occur, and a second for 1978-9 in which construction activity continues and oil is stockpiled. Both include activities associated with financing the purchases of oil and/or construction of storage facilities. For each two-year run, activities are measured in terms of an average annual rate for the two year period.

1. Construction Period, 1976-7 - Analysis of Type and Amount of Stockpile Capacity and Type of Financing

First let us look at how final demands are estimated for the 1976-7 delta runs of the combined model. For each delta

final demand to be estimated, three stockpiling variables have to be specified: the type of stockpile capacity, the size of the stockpile, and the method of financing. For example, consider the small, steel tank stockpile financed by income taxes. In this case:

$$(1) \quad Y_{(\text{small, steel tank, income tax})}^{76-7} = Y_{\text{base}}^{76-7} + \Delta I_{(\text{small, steel tank})}^{76-7} - \lambda (C_{\text{base}}^{76-7} + I_{\text{base}}^{76-7})$$

where Y_{base}^{76-7} = the base case 110-order final demand vector in 1967 \$

$\Delta I_{(\text{small, steel tank})}^{76-7}$ = the 110-order vector of average construction costs obtained from Table 1 by multiplying the required per barrel of capacity dollar amounts for steel tanks by $\frac{1}{4}$ of the total input capacity requirement and deflating the 1974 \$ amounts to 1967 \$

C_{base}^{76-7} = the base case 1976-7 110-order personal consumption vector in 1967 \$

I_{base}^{76-7} = the base case 1976-7 110-order fixed investment vector in 1967 \$

and

$$(2) \quad \lambda = \frac{\sum_{i=1}^{110} \Delta I_{(\text{small, steel tank})}^{76-7}}{\sum_{i=21}^{110} (C_{\text{base}}^{76-7} + I_{\text{base}}^{76-7})} \quad \text{or}$$

$$\lambda \left[\sum_{i=21}^{110} (C_{\text{base}}^{76-7} + I_{\text{base}}^{76-7}) \right] = \sum_{i=1}^{110} \Delta I_{(\text{small, steel tank})}^{76-7}$$

so that by definition of λ

$$(3) \quad \sum_{i=1}^{110} Y_{\text{base}}^{76-7} = \sum_{i=1}^{110} Y_{(\text{small, steel tank, income tax})}^{76-7}$$

These equations express the following economic content. Equation (1) says that the delta final demand vector will equal the original base case final demand vector plus the additions to final demand involved in building the stockpile minus the decrease in consumption and investment final demands due to the tax increase needed to finance construction. It is assumed that all types of C and I expenditures are cut back proportionally. Equation (2) insures that the aggregate decrease in C and I matches the aggregate increase in stockpile construction purchases, and equation (3) follows.

Equations (1) - (3) can be used to estimate any delta Y vector for any given combination of type and size of stockpile capacity. A comparison of the λ 's between these cases is a measure of the different income tax increases which would be needed to finance different stockpile plans during the first two year construction period.

Several other financial mechanisms besides a proportional tax on C and I are possible. The case investigated is a tax on gasoline. If a tax on gasoline of an amount Δt is imposed, it would shift the short run supply curve up by an amount equal to the tax, as in Figure 1. The price paid by consumers would increase from p_0 to p_1 while the price received by producers would fall from p_0 to p_2 . For a given tax increase, the degree to which the price will rise depends on the elasticity of the demand curve. A recent FEA survey of gasoline demand elasticity estimates found that common estimates of short run elasticity range from .10 to .20, while estimates of about .6 for the long run elasticity are common.

If the short run demand for gasoline were perfectly inelastic, as in Figure 2, and all the cross-price demand elasticities were zero, then the increase in the tax would have no effect on the quantity of gasoline produced. However, by taking greater amounts of income, the tax would lead to a decrease in real income. In this pure income effect case, equations (1) and (3) can be used to estimate the short run tax impact.

Figure 1. Supply and demand for gasoline, general case.

Figure 2. Supply and demand for gasoline, perfectly inelastic demand.

In the general case where demand elasticity is greater than zero, equation (4) is used:

$$(4) \quad Y_{(size, type, gas\ tax)}^{76-7} = Y_{base}^{76-7} + \Delta I_{(size, type)}^{76-7} - \Delta C_{gas}^{76-7} - \lambda_{gas} C_{base}^{76-7}$$

where ΔC_{gas}^{76-7} = change in quantity of gasoline purchased due to ΔC_{gas} (equal to $Q_0 - Q_1$ in Figure 1) in 1967 dollars

and

$$(5) \quad \lambda_{gas} = \frac{\sum_{i=1}^{110} \Delta I_{(size, type)}^{76-7} \Delta C_{gas}^{76-7}}{\sum_{i=21}^{110} C_{base}^{76-7}}$$

This assumes that all income elasticities are equal, and that all cross-price demand elasticities are zero.

2. Oil Purchase and Construction Period, 1978-9

During the 1978-9 period, it is assumed that the oil to be stockpiled is purchased from foreign countries and that impositions of income or gasoline taxes are used to keep final demand constant. First, let us consider the increases in the base case final demand caused by a stockpile program before taxes are imposed. The increase will equal the stockpile construction activity purchases plus increased purchases by foreigners with dollars obtained from oil sales.

Now let us consider the amount of additional dollar claims foreigners will obtain as a result of their additional oil sales to us for stockpile storage. If the supply of oil is perfectly elastic with respect to the price, as in Figure 3, then the number of additional dollars they obtain from us will be the increase in quantity bought for the stockpiles ($Q_1 - Q_0$) times the going price, P_0 , or the shaded rectangle. The case where OPEC is willing to sell us additional oil only at higher prices is illustrated in Figure 4. As before, the demand curve shifts by an amount equal to the stockpile purchase, ($Q_1 - Q_2$), only now the price rises to P_1 and the quantity of oil purchased for other uses declines (by $Q_0 - Q_3 = Q_1 - Q_2$). The net result is that foreigners accumulate additional dollars equal to the shaded area. In this case, estimations of the elasticity of the demand curve, elasticity of the supply curve, and estimates of the amount of oil purchased

previous to the stockpile purchase are all required to estimate the shaded area. The following estimates are used: elasticity of demand = 0.0, elasticity of supply = 1.0, Q_0 = 9 million barrels/day, and P_0 = \$10.75/barrel for crude (or \$10.25/barrel for residual). Given these estimates, the size of the rectangle and the price increase will vary with the size of $(Q_1 - Q_0)$, the stockpile purchase.

Let us call the shaded areas in either Figure 3 or Figure 4, ΔBOP , where

$$(8) \quad \Delta BOP = \Delta Exports_{direct} + \Delta U.S. \text{ Asset Transfer} + (\Delta Exports - \Delta Imports)_{\$ \text{ Devaluation}}$$

That is, foreigners can do three things with the dollars they get from us. They can directly buy more goods and services from us ($\Delta Exports_{direct}$); they can hoard the dollars or buy U.S. Financial assets (e.g. stocks and bonds) or real assets, (e.g. land, buildings, factories), all of which comprise transfers in U.S. assets; or they can spend the dollars to obtain other types of currencies. If they do the latter, the value of the dollar will decrease relative to other currencies, and this dollar devaluation, in turn, will lead to more U.S. exports and less U.S. imports.

Three different assumptions were made as to the relative magnitude of the three terms in equation (8):

Case 1: Dump: All ΔBOP to the foreign exchange market (100% \$ Devaluation)

Case 2: Balanced: 50% of ΔBOP to the foreign exchange market (\$ Devaluation), 25% of ΔBOP to Asset Transfer, and 25% to $\Delta Exports_{direct}$

Case 3: Recycle: 50% to Asset Transfer and 50% to $\Delta Exports_{direct}$

The increases in exports and decreases in imports lead in turn to increases in final demands for U. S. products, independent of the financing strategy. Any stockpile program involving imported oil purchases will increase base case final demands directly by three magnitudes. That is:

$$(9) \quad Y^{78-9}_{base}(\text{delta}) - Y^{78-9}_{base} = \Delta I^{78-9} + \Delta Ex^{78-9}_{direct} + (\Delta Ex - \Delta Imp)^{78-9}_{\$ \text{ Devaluation}}$$

Empirical values of the 110-order inter-industry composition of ΔEx_{direct} for various stockpile systems and for the various balance of payments cases were obtained by assuming the

Figure 3. Foreign oil market, perfectly elastic supply.

Figure 4. Foreign oil market, rising supply curve.

structure of $\Delta Ex_{direct}^{78-9}$ equals the structure Ex_{base}^{78-9*} .

Empirical values of the $(\Delta Ex - \Delta Imp)_{Devaluation}^{78-9}$ vector were obtained by applying estimates of aggregate import and export elasticities obtained from Almon (1). Then using 110-order export and import price elasticities again obtained from Almon (1), the structure of $(\Delta Ex$ and $\Delta Imp)_{Devaluation}^{78-9}$ was estimated.

After these balance of payments adjustment variables are calculated, the analysis of financing follows as before. That is, in the case of income taxes used to keep the GNP constant, the delta vector is now

$$(10) \quad Y^{78-9}(\text{delta}) = Y_{base}^{78-9} + \Delta I^{78-9} + \Delta Ex_{direct}^{78-9} + (\Delta Ex^{78-9} - \Delta Imp_{Devaluation}^{78-9}) - \lambda (C_{base}^{78-9} + I_{base}^{78-9})$$

where $\lambda =$

$$(11) \quad \frac{\sum_{i=1}^{110} \Delta I^{78-9} + \sum_{i=21}^{110} Ex_{direct}^{78-9} + \sum_{i=21}^{110} (\Delta Ex^{78-9} - \Delta Imp_{Devaluation}^{78-9})}{\sum_{i=21}^{110} (C_{base}^{78-9} + I_{base}^{78-9})}$$

Also, as in (4), a λ_{gas} can be estimated and used to calculate the decrease in base case consumption to balance the delta and base case final demands.

3. Use of Combined Model

Once these final demand estimates are calculated, the rest of the analysis follows. One plugs in the different delta vectors in the combined model, and solves for outputs, labor requirements, and capital requirements for 110 different industries. These solutions are compared with the solutions obtained using base case final demands. The analysis becomes more complicated where relative energy costs change due to import price increases and/or excise tax increases. As previously indicated, in these cases, the relative costs in the objective function of the linear program must also be adjusted.

V. Final Results

A variety of variables associated with the construction and financing of a national oil stockpile have been examined in this demonstration application of Brookhaven's Energy I-O Model. For

* In fact, in 1974 most exports were military goods.

each variable a range of assumptions has been examined which account for alternative policy decisions at the national level and/or uncertainty as to how the economy might respond to the stockpile program. This section presents, in turn, the range of economy-wide impacts that can be expected, given the range of assumptions for each policy variable; i.e., sensitivity to the choice of stockpiling facility, method of financing, etc.

The results can be more safely interpreted in qualitative rather than quantitative terms since certain data sources employed by Brookhaven may have been imprecise and out-of-date. Also, model inputs were not reviewed by the project sponsor or by experts in respective fields. Nevertheless, the authors believe these results do identify many of the areas in which a stockpile program would have significant impact on the nation's economy, and they suggest directions for additional research on the topic.

1. Stockpile versus No Stockpile

Given a single set of assumptions for the variables examined, the effects of this one particular stockpile scenario are examined with respect to a Base Case in which there is no stockpile program. Base Case Assumptions are listed in Table 3.

Table 3. Base Case Assumptions

	<u>1976-77</u>	<u>1978-79</u>
1. GNP (1967 dollars)		
Personal Consumption Expenditures	700.8	775.2
Gross Private Fixed Capital Formation	111.1	124.7
Government Expenditures	105.7	110.0
Inventory Change	11.2	10.4
Exports	72.4	79.7
Imports	- 57.1	- 63.4
	<u>944.1</u>	<u>1036.6</u>
2. Sectoral Energy Production (10^{15} Btu)		
Coal	13.56	15.38
Crude Oil & Gas	45.89	45.95
Refined Oil Products	25.59	27.07
Pipeline Gas	22.19	22.21
Fossil Electric	5.25	5.66
LWR Electric	.33	.49
Hydroelectric	1.02	1.02
3. Domestic Energy Consumption (10^{15} Btu)		
Coke	1.39	1.54
Chemical Feedstocks	4.30	4.68
Motive Power	3.97	4.27
Process Heat	9.06	9.87
Water Heat	1.48	1.57

Table 3. Base Case Assumptions
(Continued)

	<u>1976-77</u>	<u>1978-79</u>
Space Heat	7.17	7.58
Air Conditioning	1.59	1.85
Electric Power	4.03	4.39

The set of stockpile assumptions chosen are as follows:

Type of Capacity = 75% in leached salt domes: 25% in steel tanks

Size = large stockpile - 4380 million barrels

Products = 75% crude oil/25% residual fuel oil

Source of Oil = Imported

Financing = Income tax

Price Elasticity = None

Balance of Payments = Balanced - 50% of petrodollars to foreign exchange market, 25% to direct export demand, 25% to capital asset transfers.

This section thus shows the general magnitude of effects caused by a stockpile program. Other sections then go on to examine sensitivity of the effects with respect to each policy and behavioral variable.

A stockpile of 4380 million barrels in which all oil is purchased in a two year period would have major impact on the structure of Gross National Product (GNP)*. Although in the first two years of the program (construction only) GNP is affected minimally, in the second two years (construction plus oil purchase and stockpile) inventory purchases more than double (2.62 times Base Case) and net exports exclusive of oil increase by 35%. Personal consumption expenditures in the second two years drop 1.8% because of the increased income tax needed to finance the stockpile. The drop in business capital spending resulting from increased corporate income taxes is more than offset by construction activity for stockpile facilities and capacity expansion in export industries. Total GNP purchases of capital goods increase by 1.7% during the second two years. Major GNP effects of the large stockpile program are summarized in Table 4.

* Full employment is assumed for all model runs so the level of GNP is constant, with or without a stockpile program, by assumption.

Table 4. GNP Change Due to an Oil Stockpile Program
Case 8 Versus Base Case GNP

	<u>1976-77</u>	<u>1978-79</u>
Inventory Change	0	+161.5%
Net Exports (exclusive of oil)	0	+ 35.0%
Personal Consumption Expenditures	-0.2%	- 1.8%
Gross Private Fixed Capital Formation	+1.1%	+ 1.7%

The shift in the structure of production during the first two years primarily reflects reallocation of resources to build stockpile facilities. The largest increases in output occur in the Other New Construction; General Industrial Machinery & Equipment; Heating, Plumbing & Structural Metal Products; and Water Transportation sectors. The increased taxes needed to finance this construction cause a reduction in consumer and business expenditures. Output thus drops in such sectors as New Residential, Non-Residential, and Public Utility Construction; Farm Machinery; Furniture & Fixtures; and Materials Handling Equipment. Selected changes in sectoral output over the Base Case are shown in Figure 5.

Figure 5. Sectoral change in output, case 8 versus base case, 1967-77.

During the second two years of the program changes in output over the Base Case are greater because of the large foreign oil purchases. The greatest increase in output occurs in the Water Transportation Sector. More ships are needed to import the oil, transport the stockpile construction materials, and most importantly, to transport the exports which would be required to pay for the oil imports. Payments to foreigners for the oil boosts export demand, and sectors benefitting include Tanning and Industrial Leather Products, Office and Computing Machines, and Industrial Machinery & Equipment. The largest drops in output are concentrated in consumer oriented industries. With a higher tax bite there is less demand for Medical & Educational Services, Apparel & Footwear, Hotels and Lodging, Furniture, and Residential Maintenance & Repair Construction. Figure 6 depicts selected changes in output for the 1978-79 period over the Base Case.

Employment information in the model is presented in terms of man-year requirements by sector. During 1976-77 the greatest increases in employment are in the Heating, Plumbing & Metal Products sector and in the General Industrial Machinery & Equipment sector. Other employment increases associated with construction activity occur in Water & Motor Freight Transportation, Stone & Clay Products, Railroads, and Fabricated Metal Products. The largest employment decreases occur in New Residential Construction and Wholesale & Retail Trade. Other 1976-77 employment changes are shown in Figure 7.

During the 1978-79 period, the largest employment changes are losses--Wholesale & Retail Trade, Medical & Educational Services, Finance & Insurance, and Hotels & Lodging. Employment gains occur in export-oriented industries (primarily agricultural and capital goods) and in the Water Transportation sector. Selected changes over the Base Case are shown in Figure 8.

2. Type and Size of Stockpile Facility

Costs of construction and of oil to be stockpiled are, of course, primary factors in determining the type and size of facility to be built. While cost estimates used in this study are rough and not examined in any great depth, it is felt that they do indicate rough orders of magnitude existing between the types of stockpiling facilities considered. The economic impacts of the differing bills of materials and services for each facility type have been estimated with the Energy I-O Model in much greater detail. In general, these impacts are linear with respect to stockpile size, and they will only be presented for the 730 million barrel stockpile.

Construction of steel tanks would require the largest reallocation of labor and capital due to their higher cost; nuclear-salt and nuclear-rock programs the least. If the program were financed by personal and corporate income taxes, steel tanks would require the largest increase in the tax rate

Figure 6. Sectoral change in output, case 8 versus base case, 1978-79.

Figure 7. Sectoral change in employment, case 8 versus base case, 1976-77.

Figure 8. Sectoral change in employment, case 8 versus base case, 1978-79.

and nuclear salt domes the least. This increase would be fairly small, reducing consumer and fixed investment purchases less than 0.4% over the Base Case for any of the cases with a small stockpile. On the other hand, income tax financing of a 4380 MM barrel stockpile would reduce consumer and investment purchases on the order of 2-3%. With a large stockpile it might be desirable to stretch the purchasing and financing of oil over more than two years.

The steel tank program uses slightly more coal and refined oil products than underground storage programs. Greater demand for energy-intensive steel components are the primary reason, and this is reflected in increased demand for coke, process heat and electricity.

Shifts in the structure of production in the economy with a steel tank program versus an underground program mainly reflect two factors: (1) the different mix of materials and services needed to construct storage facilities, and (2) a greater decrease in consumer expenditures with the steel tank program because of higher income taxes.

3. Financing

Two methods for financing the program are examined. These are an increase in the personal and corporate tax rate and an increase in the federal gasoline tax. For income tax financing, both a supply elasticity of 1.0 and a perfectly elastic supply curve for foreign oil are analyzed. For the gasoline tax, a demand elasticity of -0.1 with a perfectly elastic supply curve are assumed. Comparisons presented below are for the large stockpile with 25% stored as resid in steel tanks and the rest stored as crude in leached salt domes, and with the "Dump" balance of payments assumption.

Income tax financing (assuming infinite oil supply elasticity) reduces consumer expenditures and business capital spending by 0.16% over the 1976-77 Base Case and by 2.02% over the 1978-79 Base Case. With all of the petrodollars being dumped on the foreign exchange market, other U. S. imports drop and exports go up. The aggregate level of net exports exhibits no change.

With a foreign oil supply elasticity of 1.0 the price of oil rises about 50% in 78-79, and demand for imported oil drops slightly. Higher taxes are required causing consumer capital good expenditures to drop by 3.89% over the 1978-79 Base Case--\$35.1 vs. 16.3 billion (in 1967 dollars). Thus, the greater the rise in international oil prices, the greater the reallocation of productive resources to export goods and away from consumer goods and services.

When a gasoline tax is used to finance the stockpile, such a tax would raise the price of gasoline to consumers by 5% in 1976-77 and by 69% in 1978-79. Demand for gasoline would drop, as would demand for imported petroleum (though by less than 1% from the income tax financing case). Looking at the economy as a whole, the structure of production and the composition of GNP other than consumer purchasing patterns would be little changed from the income tax financing case which assumed infinite oil supply price elasticity. Consumer purchases would probably follow the patterns of the Arab Oil Embargo period, a reduction in demand for autos and auto services, travel, and away-from-home lodging.

4. Balance of Payments

The parameterization on balance of payments was made under the constant assumptions of a large stockpile ($\frac{1}{4}$ refined and in steel tanks, $\frac{3}{4}$ crude and in leached salt domes), financing by income taxes on persons and corporations, zero price elasticity of demand, and infinite price elasticity of supply.

In general, the more that foreigners buy U. S. capital assets with their petrodollars, the less their effect on reallocation of capital and labor in the U. S. economy. As shown in Table 5, final demand purchases of capital goods and net exports increase the least and consumer purchases decrease the least under the "Recycle" assumption where 50% of the petrodollars are used to purchase U. S. assets. Also, the greater the proportion of petrodollars that are dumped on the foreign exchange market, the greater the fall in U. S. imports. Under the "Dump" assumption, U. S. production would be stimulated in such import oriented industries as food, lumber and wood products, paper and paper products, iron and steel manufacturing, non-ferrous metals, and motor vehicles.

In summary, it has been shown that the framework of the combined model allows for the incorporation of a wide range of economic variables that are ignored by many energy models. Analysis of the effects of income elasticities, price elasticities, tax rates, exchange rates, and mechanical heat rates produce results which are both meaningful and useful for policy analysis.

Table 5
Balance of Payments Impacts, 1978-79
(billions of 1967 dollars)

	<u>Base Case</u>	<u>Dump*</u>	<u>Balanced**</u>	<u>Recycle***</u>
Non-Energy Net				
Exports	36.7	54.5	50.1	45.6
Total Net				
Exports	16.3	16.3	11.9	7.5
Consumer				
Purchases	775.2	756.6	761.4	766.2
Capital Goods				
Purchases	124.7	127.1	126.8	126.5

* 100% of petrodollars to foreign exchange market.

** 50% to foreign exchange market, 25% to direct demand for U. S. exports, 25% to purchase of U. S. assets.

*** 50% to direct demand for U. S. exports, 50% to purchase of U. S. assets.

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APPENDIX
A Two-Level Iterative Model Used
for Energy Policy Analysis

The combined model is a combination of an optimization model of the national energy system and an input-output model for the entire economy.* This provides an analytical framework for evaluation of economy-wide impacts of future technological change due to resource substitution or to the introduction of new energy technologies, as well as evaluation of the effects of changes in consumer investment and foreign trade behavior in the energy sector.

The Input-Output Model

Output of energy sectors is expressed in physical units (Btu) instead of in dollars. A significant feature is that the output of the traditional energy sectors (e.g., crude, refined oil, gas, coal, electricity) is not distributed directly to other sectors. Instead, these traditional outputs of the energy supply/conversion sectors are distributed to eight dummy energy product sectors. Product sectors define nonsubstitutable end-use demands for energy -- coke, petrochemical feedstocks, motive power, process heat, water heat, space heat, air conditioning, and electric power.

Energy use by producing sectors of the economy is respecified in terms of these energy products rather than in terms of generated electricity and specific fuels such as coal or natural gas. By specifying input requirements in terms of energy products such as space heat, substitution among fuel supplies is permitted, and a single production function for non-energy sectors suffices. Technological change associated with fuel substitution is localized in the production functions of energy supply/conversion sectors.

The revised input-output coefficient of production matrix is depicted in Figure 1. Outputs of the energy supply and energy product sectors are measured in physical units, British Thermal Units (Btu), and outputs of the non-energy sectors are measured in dollars. Production coefficients in the A_{GG} , A_{GP} , and A_{PS} submatrices have units of Btu/Btu in the A_{PI} submatrix Btu/\$, in the A_{IS} submatrix \$/Btu, and in the A_{II} submatrix \$/\$. A_{PP} and A_{IP} coefficients are zero because energy product sectors are dummy, non-productive sectors. The A_{SI} coefficients are zero because

* A complete description of a combined model is contained in "A Two-Level Iterative Model for Estimating Inter-Fuel Substitution Effects," Behling, David J., et al., BNL Report No. 19863, March, 1975.

	ENERGY SUPPLY SECTORS	ENERGY PRODUCT SECTORS	NON- ENERGY SECTORS	FINAL DEMAND	TOTAL OUTPUT
ENERGY SUPPLY SECTORS (Btu)	A_{SS}	A_{SP}	0	Y_S	X_S
ENERGY PRODUCT SECTORS (Btu)	A_{PS}	0	A_{PI}	Y_P	X_P
NON-ENERGY SECTORS (\$)	A_{IS}	0	A_{II}	Y_I	X_I

Figure 1. Energy input-output model.

sectoral energy use is described in terms of final energy products via the A_{PT} coefficients.

Outputs of the supply sectors are measured in terms of resources or converted energy forms. The resources include Btus of raw, extracted coal, and crude extracted oil and gas. The converted energy forms include refined oil products, pipeline gas, electricity generated by fossil fueled plants, electricity generated by light water nuclear reactors, and electricity generated by hydroelectric plants.

An optimization model will next be described whose solution can be used to estimate all of the A_{SS} and A_{SP} input-output coefficients.

Brookhaven Energy System Optimization Model

The Brookhaven Energy System Optimization Model (BESOM) is a linear programming model in which the total cost of satisfying a given set of national energy product requirements is minimized. Given a set of energy requirements defined by end use (i.e., motive power, space heat, electric power) and a set of available energy resources and conversion technologies, the model determines the minimum cost allocation of energy supplies to meet energy demands. For instance, it determines the annual coal and oil requirements of electric generating plants, the quantities of oil and electricity directed to space heat, and the refined oil/electricity mix to meet the demand for motive power.

The important characteristics of the model may be summarized as follows:

1. The model encompasses the entire energy system including all alternate resources and both electric and non-electric demands.
2. The full feasible range of interfuel substitutability is reflected.
3. Technical, economic, and environmental characteristics of energy conversion devices (both supply and utilization) are incorporated.
4. The load-duration characteristics of electrical demands are included. (This is a very important element that is frequently ignored in energy system modeling.)
5. Supply, demand, and environmental constraints are specified exogenously.
6. Optimal supply-demand configurations are indicated by the model.

The model is formulated about the classical transportation problem of determining the optimal routing of a product, in this

case an intermediate energy form, from a set of n supply nodes to m demand nodes where a cost and a set of environmental impacts are identified for a unit of energy passing over each of the $n \times m$ possible paths. The typical linear programming representation of the transportation problem is modified by the inclusion of efficiency coefficients in the supply and demand constraints and by additional constraint equations reflecting environmental and certain technical features of the energy system.

To provide a feasible path between a supply and demand category, both a supply and utilizing technology must be identified. For a given path, j , a resource S_u is converted to intermediate energy form z_j , at an efficiency, e_{uj} . In turn, the intermediate energy form is used to satisfy demand D_v at an efficiency d_{vj} . Additional constraints G_y are placed on certain plant capacities and on electrical peaking and balance requirements. A cost c_j is also defined per unit of intermediate energy form.

In the model the intermediate energy form is defined at the point just before end-use. Examples of intermediate energy forms include transmitted and distributed electricity, gasoline in an automobile, and fuel oil in a home oil tank. The supply efficiency is calculated by multiplying together all the supply efficiencies on a path from the resource to the intermediate energy form; similarly the demand efficiency is calculated by multiplying together all the demand efficiencies on the path from the intermediate energy form to final demand. The efficiencies and environmental impacts associated with each activity in BESOM are taken from the Energy Model Data Base.

The mathematical formulation of the model is as follows:
Minimize

$$\sum_{j=1}^P c_j z_j$$

subject to

$$\sum_j \frac{1}{e_{uj}} z_j \leq S_u \quad u = 1, n$$

$$\sum_j d_{vj} z_j = D_v \quad v = 1, m$$

$$\sum_j g_{yj} z_j \leq G_y \quad y = 1, h$$

and

$$z_j \geq 0.$$

The summation in each constraint equation is over only those indices j that represent admissible intermediate energy forms for the supply category, demand category, or other constraint. The full linear program array thus has $k = n + m + h$ constraints.

There are several basic types of constraint equations which are used in the model formulation: supply, capacity, demand, peaking and balance, and other.

Supply equations limit the amount of a given resource which may be used in the planning year, either in total use or for a specific purpose. For example, there is a total natural gas consumption constraint, as well as an equation limiting the total inputs of natural gas to steam electric plants.

Capacity equations limit the generating capacity of plant types, and are particularly applicable to such categories as hydro-electric, geothermal electric, and solar electric, though they may be used for others as well. Coefficients in a capacity equation depend upon the plant factor of the generating device and upon the load factor of the demand it serves. These concepts are defined below.

The load factor represents the demand duration. It is a characteristic of the demand or consumption of energy and is defined as the ratio of the average rate of demand over a given period of time, such as a week or a year, to the peak rate occurring in the period.

The plant factor is similarly defined as the ratio of the average power of a generating plant over a given period of time to the peak power for which the plant is rated. The plant factor is characteristic of the supply, or generation of energy. A load factor of 1.0 represents what is called "base load demand" or a plant which meets demands having lower load factors but which is able to fully utilize its off-peak generating capacity.

Demand equations describe how intermediate energy forms meet demands. An intermediate energy form satisfying a demand does so at a certain efficiency. The efficiencies represent the relative effectiveness of different fuels and devices in meeting demand. Demand type equations are also specified which limit the amount of demand which may be met by certain technologies.

Peaking and balance equations are used in modeling the electric sector. Primary load factors and cyclic characteristics have been predetermined for each of the demands that can be satisfied with electrical energy. The primary load factor designates the load factor at which the major fraction of the energy is required. For every Btu of intermediate energy form generated for use by a demand category at the primary load factor, additional Btus are generated in order to meet both the peak and intermediate load

associated with that demand category.

An endogenous peaking demand equation requires that the demand for electric energy at the peak load factor, which was created by a reassignment of portions of higher load factor demands satisfied with central station electric power, must be met by devices which operate at the 0.1 load factor.

An "employ peaking devices" equation restricts the percentage of electricity that may be generated at the 0.1 load factor by central station plants. This reflects the fact that peak demand of a stochastic nature will always be present and cannot be totally eliminated by improved load scheduling.

Additionally, equations are specified for daily peak, seasonal peak, and off-peak constraints.

The coefficients in the objective function reflect the capital cost of the facilities used in the energy supply system as well as fuel and other operating costs. (Social costs, or externalities, may also be included if these can be quantified. The capital and operating cost of utilizing devices such as home furnaces, air conditioners, automotive engines, and blast furnaces will be included in the future.) The typical cost coefficient is therefore made up of the sum of at least three cost elements: a capital recovery cost, c_c ; a fuel cost, c_f ; and an operating, maintenance, transportation and distribution cost, c_m . In general, the fuel cost will include the capital recovery cost of any fuel extraction and treatment facilities that are required.

The Combined Model

Use of either the energy optimization model or the input-output model to portray the future in isolation has drawbacks. Although alternative energy technologies are now contained in the input-output framework, the model cannot internally determine the extent to which each is utilized in some future planning year. Alternatively, the optimization model is weak in macroeconomic content. Supplemental information on Gross National Product and its components or on inter-industry demand for energy cannot be easily related to the specification of energy demands which drives the model.

Combination of the models reduces the a priori judgments that must be made before running either model. With the input-output model, one no longer must specify A_{gg} and A_{gp} coefficients, those which describe fuel flows and conversion into end-use energy products. These are determined by a BESOM solution. With the input-output model one no longer must specify total demands for energy products. Instead, only those portions which comprise final demand in an input-output sense, i.e., that which is included in compilation of GNP, must be predetermined. Interindustry (sectoral) input demands for energy products are obtained through solution of the I-O model. Thus, solution of the input-output model with

an estimated vector of final demand (GNP) gives total energy product consumption that can be used as demand constraints for BESOM.

Solution Technique for Combined Model

At the present time this two-level model is solved by iteration. The solution sequence is as follows:

1. Develop a projected final demand vector for the I-O representing GNP for the planning year being analyzed. Insert into BESOM appropriate costs, capacities, and other constraints for this planning year.

2. Run the I-O model to determine basic energy demands, or total outputs of the eight energy product sectors, associated with the GNP projection. A_{ss} and A_{sp} coefficients can start out equal to zero, or approximate values can be inserted to reduce running time to convergence.

3. Disaggregate Basic Energy Demands to obtain appropriate demand equation constraints for BESOM.

4. Run BESOM with disaggregated energy product demands to determine energy supply-demand configuration, the set of z_j energy flows.

5. Convert BESOM output to A_{ss} and A_{sp} coefficients and insert these into I-O model.

6. Perform iterative runs, testing for convergence of Basic Energy Demands after each iteration.

Figure 2 depicts this solution sequence pictorially. The interface between the models consists of two sets of equations: one calculating demand constraints for the linear programming model from the total outputs determined by the I-O, and the other calculating input-output coefficients from the solution to BESOM.

Policy variables within the combined model include energy supply, capacity, and other BESOM constraints, the input-output Y vector of final demand, and certain A Matrix coefficients, particularly energy product coefficients which can be changed to reflect energy conservation by producing sectors.

Figure 2. Solution sequence.