To benchmark these numbers against another scenario, we have computed the change in consumers' surplus for the "cheap SNG" case used in the ERDA Fossil Energy Prioritization study. In that study, the same base case was compared to a case in which first generation coal gasification economics were left unchanged. However, second generation coal gasification capital and operating costs were decreased by 30%; hydrogen, methanol, and other technologies based on gasification were decreased by 15%, and the long run economics of integrated low Btu gasification/combined cycle facilities were decreased by 15%. These changes are much larger than the changes assumed in the commercialization scenario and should lead to much more significant changes in consumers' surplus. Table 4.46 illustrates the same calculations for the base case relative to the "cheap SNG" case that we illustrated above for the base case relative to the early SNG case. Note in the cheap SNG case that the net present change in consumers' surplus exceeds that in the early SNG case by about a factor of 20. Thus, it is interesting to note that any alternative that can actually decrease the long run economics of second generation coal gasification technologies pays significantly more benefits than an option which merely accelerates the availability of those technologies under base case assumptions. It bears repeating that neither of these scenarios represents the long run benefits of commercial demonstration. They are simply hyopthetical scenarios which are potential outcomes of commercial demonstration.

PRODUCERS' SURPLUS

Turning now to producers' surplus, we have assumed for the purposes of illustrating the change in producers' surplus that surplus benefits to foreign producers are included neither as a cost nor as a benefit of the program. Although this assumption is not necessarily correct, the method by which foreign producers' surplus is calculated by the model is a very crude approximation to the supply/demand balance in the world. Hence, that number would be questionable, regardless. Table 4.47 contains the U.S. producers' surplus in the base case and in the early SNG case. The numbers contained in that table are annual figures in billions of dollars per year summed across all production of primary resources in

TABLE 4.46

Change in Consumers' Surplus

Cheap SNG Case Relative to Base Case

(Net Present Value at 10%; Billions of 1975 Dollars)

Change in Consumers' Surplus	$43.3 Billion

PRODUCERS' SURPLUS (BILLION $/YR)

	BASE CASE (without commercial demonstration plant)	EARLY SNG CASE (with commercial demonstration plant)
	U.S. PRODUCERS	U.S. PRODUCERS
1975	48.2	48.4
1977	60.4	60.5
1980	66.7	66.6
1983	73.9	74.1
1986	76.5	77.4
1989	78.8	78.5
1992	80.1	78.8
1995	77.9	76.3
1998	73.2	72.0
2001	66.1	65.4
2004	61.0	61.4
2007	52.9	53.0
2010	47.2	46.4
2013	42.7	41.2
2016	36.7	36.5
2019	31.0	33.5
2022	26.1	27.8

TABLE 4.47

the Lower Forty-eight and Alaska. Calculations similar to the ones described earlier are made for each primary resource in the U.S. and accumulated by the model during the final iteration. Because certain of the resources are the most difficult aspects of the model to converge (resources having very steep supply curves), the accuracy of this calculation is very much dependent on the degree of convergence of the model. As we noted above, our goal in computing these hypothetical cases was not to converge the model to an extremely fine level. Therefore, the U.S. producers' surplus indicated in Table 4.47 should be regarded as very approximate. Using these numbers, we subtract the U.S. producers' surplus in the base case from that in the early SNG case to get the annual change in producers' surplus under this early SNG scenario. Finding the intra-period net present value of the annual producers' surplus, and then discounting these to the base year of 1977, one arrives at a figure of -$1.2 billion, which was indicated in the Executive Summary. Even though this change in producers' surplus is approximate, it is encouraging that the direction of this change appears correct. As a technology is made more attractive, one expects the producers of depletable resources to extract less rent, and thus the producers' surplus should decline. To illustrate an extreme case, suppose that today's producers of natural gas knew that advanced synthetic gas could be produced at, say, $2.00/MMBtu by the year 1985. Their propensity to withhold production of their gas, waiting for higher prices, would certainly be lessened knowing that they may not be able to compete with that $2.00 gas once it is available. Therefore, they are likely to sell today's gas at slightly cheaper rates. The producers' surplus and economic surplus calculations for the early SNG case are summarized in Table 4.48.

LONG RUN ENVIRONMENTAL IMPACTS

The SRI National Energy Model includes a submodel that calculates environmental residuals in each of nine demand regions and thirty supply regions in the country. The residuals accounted for are:

SO_x emissions
NO_x emissions
CO emissions
HC emissions

TABLE 4.48

Change in Consumers' and Producers' Surplus

Cheap SNG Case Relative to Base Case

(Net Present Value at 10%; Billions of 1975 Dollars)

Change in Consumer's Surplus	$43.3
Change in Producers' Surplus	-17.7
Change in Economic Surplus	25.6

Particulates emitted

Aldehydes emitted

Shale waste production

Non-shale fossil fuel waste production

Radioactive waste production

Land requirements

Water requirements

The first six pollutants are air pollutants and the remainder involve solid and liquid waste products or resource requirements. The water pollutants output from the local model are aggregated in non-shale fossil fuel waste production. We will briefly discuss the methodology used to keep track of each environmental residual in each region.

Suppose for every technology we know the following information:

lb SO_x/MMBtu Output

lb NO_x/MMBtu Output

.

.

.

acre-ft water required/MMBtu Output

That is, we know the emission rate per MMBtu of output for every residual and every technology. Figure 4.38 illustrates for the case of electric power generation from coal. If we know the power generated over time, we can easily calculate the quantity of each pollutant and the water requirements over time as a result of electric power generation using this technology. These emission rates are input for all elements of the national energy system. Figure 4.39 shows part of the energy model network, and the residual production associated with it.

Adding the pollution rates by pollutant type and the resource requirements over all technologies in a region, we obtain the regional time and resource requirement over time.

ENVIRONMENTAL EFFECTS

EXAMPLE: COAL-FIRED POWER GENERATION

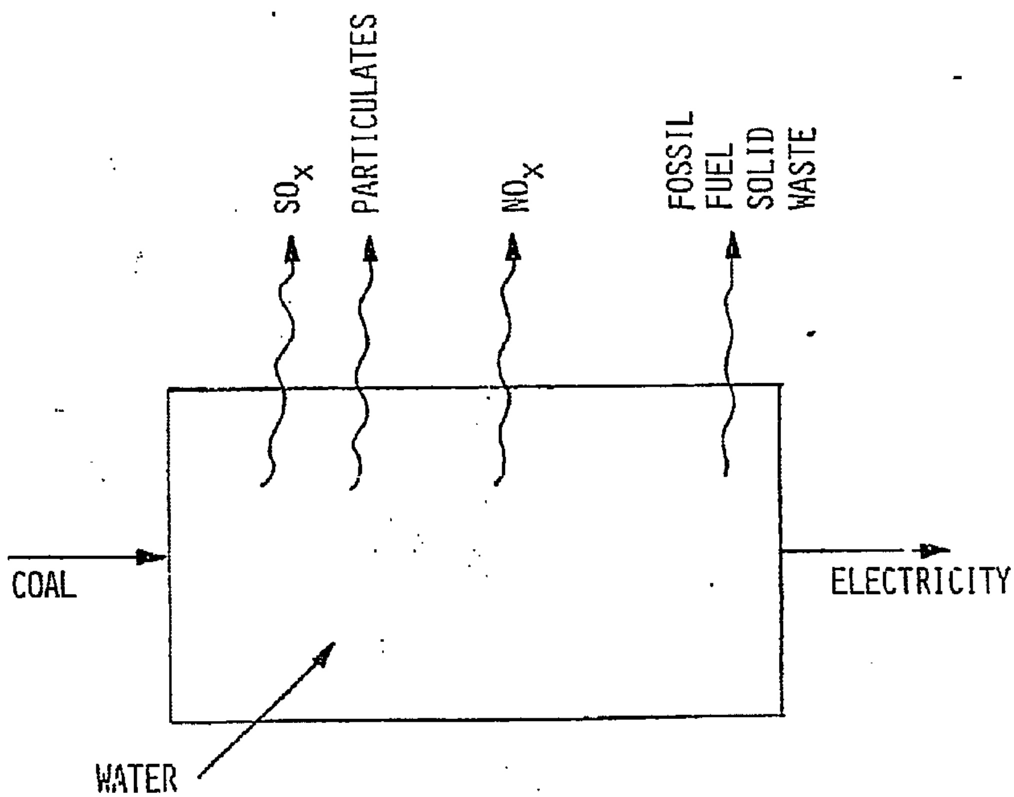


Figure 4.38

ENERGY NETWORK – PARTIAL EXAMPLE

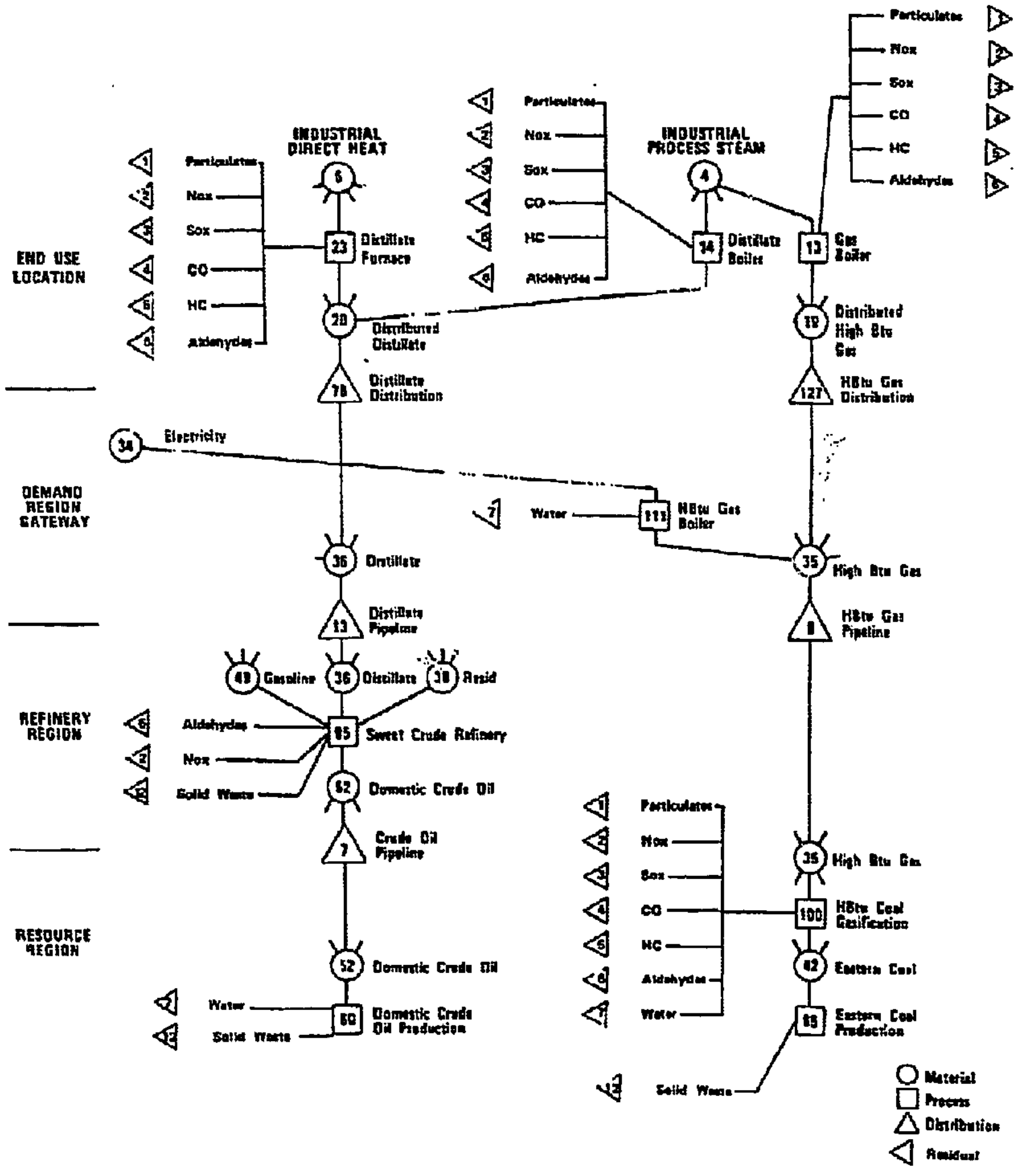


FIGURE 4.39

Suppose we plot SO_x emissions over time in the local coal-producing region in which the commercial gas plant will be located and in the demand region where the gas from the plant will be consumed in both the bid acceptance and rejection cases. We might expect to see plots such as those in Figure 4.40 in which SO_x emissions increase in the coal region near the plant, but decrease in the demand region as a result of burning the clean synthetic gas rather than some less clean fuel. Clearly, we need a self-consistent way of calculating such curves.

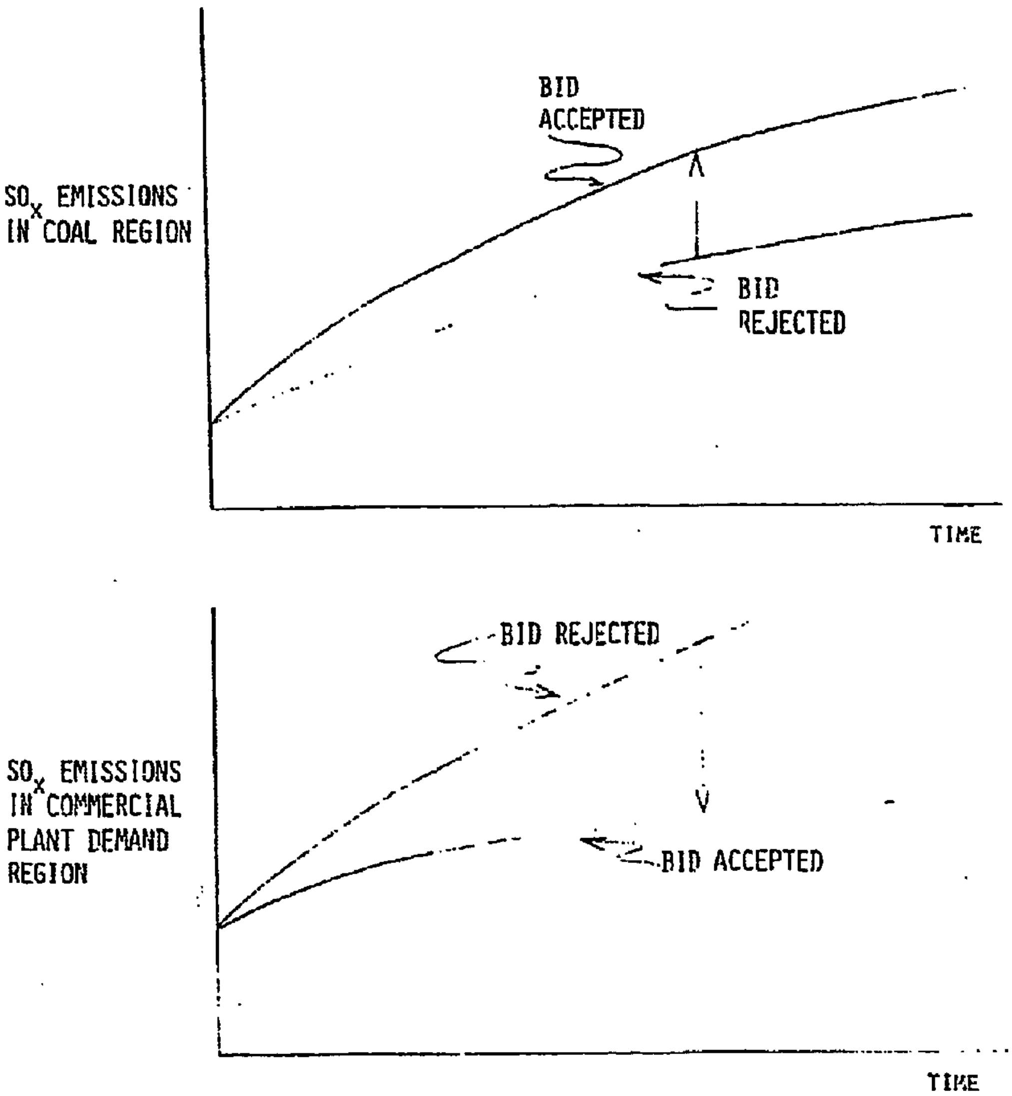
The SRI National Energy Model has been modified to explicitly calculate regional production of the eleven residuals listed above in a way that is consistent with the economic effects discussed in the previous section. The model calculates a supply/demand balance and then calculates regional residual projections consistent with the regional supply/demand balance. It is important to note that simulating dicision making by each economic agent (oil producers, auto owners, utility executives, etc.), the model assumes that decision makers <u>ignore</u> local environmental residual production in selecting among fuel types. That is, residual levels are not endogenized into the submodels that simulate decision making. The residual model used in this study, then, is merely an "accounting" model that computes residuals on a regional basis. The assumption that residual levels do not enter into individual decision making may impair the model's predictive capability in scenarios where the level of at least one undesirable residual is high in some region of the country.

<u>BASE CASE RESULTS - LONG RUN ENVIRONMENTAL IMPACTS</u>

The environmental residual submodel of the SRI National Energy Model has been run for the base case. To calculate the impact of the program, it is necessary to see the change in emissions when the base case is compared with an energy model run with no program. The base case for this analysis assumes that a commercialization program is successful in accelerating the availability of synthetic natural gas (both first and second generation) and allied technologies such as the production of methanol

FIGURE 4.40

ENVIRONMENTAL EFFECT



from coal. Qualitatively this reduces the price of SNG in the early years of technology availability. These years are the early 1990's. This price reduction improves the competitive position of high Btu gas from coal, which causes an increase in market share. Thus, activity should increase in the producing regions for coal gasification and pollution may be reduced in the demand region if SNG displaces other energy sources.

The Powder River Basin in Wyoming has one of the world's largest coal deposits. Under SNG acceleration, energy production increases in the area in the early 1990's; SNG output is 2.2 quads in 1994 with a commercialization program, and .3 quads in 1994 without one. Thus, air pollution should increase as a consequence. Table 4.49 shows the tons of air pollution emissions associated with energy production in the Powder River Basin in 1994. All of the residuals increase, and with the largest change in nitrogen oxides, an emission associated with coal gasification.

Much of the SNG produced in the Powder River Basin is transported to the North East Central demand region, a geographic area that includes the Midwestern Great Lakes states and the major cities of Chicago, Detroit, and Cleveland. In 1994 this area receives 1.1 quads of SNG when the technology availability is accelerated, versus only .2 quads without a program. While the SNG partially displaces high Btu gas from other sources, the market share for gas increases, displacing other fuels which produce higher emissions. Table 4.50 shows the tons of air pollutants in the demand region caused by the end use demand for energy. Notice that the increases are in parenthesis, denoting negative numbers, or decreases, in the air pollution quantities. The significant reductions are in particulates, nitrogen oxides, and sulfur oxides, three emissions not associated with clean-burning high Btu gas. Other residual levels are essentially unchanged.

The above discussion has looked at some specific residuals at a point in time in two geographic areas. The complete set of long run environmental impacts is a very complex list: eleven residuals for thirty-nine demand and resource regions for each of fifty years. The dimensionality

RESIDUAL

	Particulates	NO_x	SO_x	CO	Hydrocarbons
No Program	46,156	572,880	109,243	36,767	10,370
SNG Acceleration	51,767	701,198	137,638	43,962	12,934
Increase	5,611	128,318	28,395	7,195	2,564

AIR POLLUTION RESIDUALS IN TONS, 1994, POWDER RIVER BASIN

TABLE 4.49

RESIDUAL

	Particulates	NO_x	SO_x	CO	Hydro-carbons	Aldehydes
No Program	3,041,005	3,916,081	3,792,772	699,570	91,505	7,258
SNG Acceleration	2,975,401	3,834,264	3,715,347	695,944	91,695	7,226
Increase	(65,604)	(81,817)	(77,425)	(2,626)	190	(32)

AIR POLLUSTION RESIDUALS IN TONS IN 1994, NORTH EAST CENTRAL DEMAND REGION

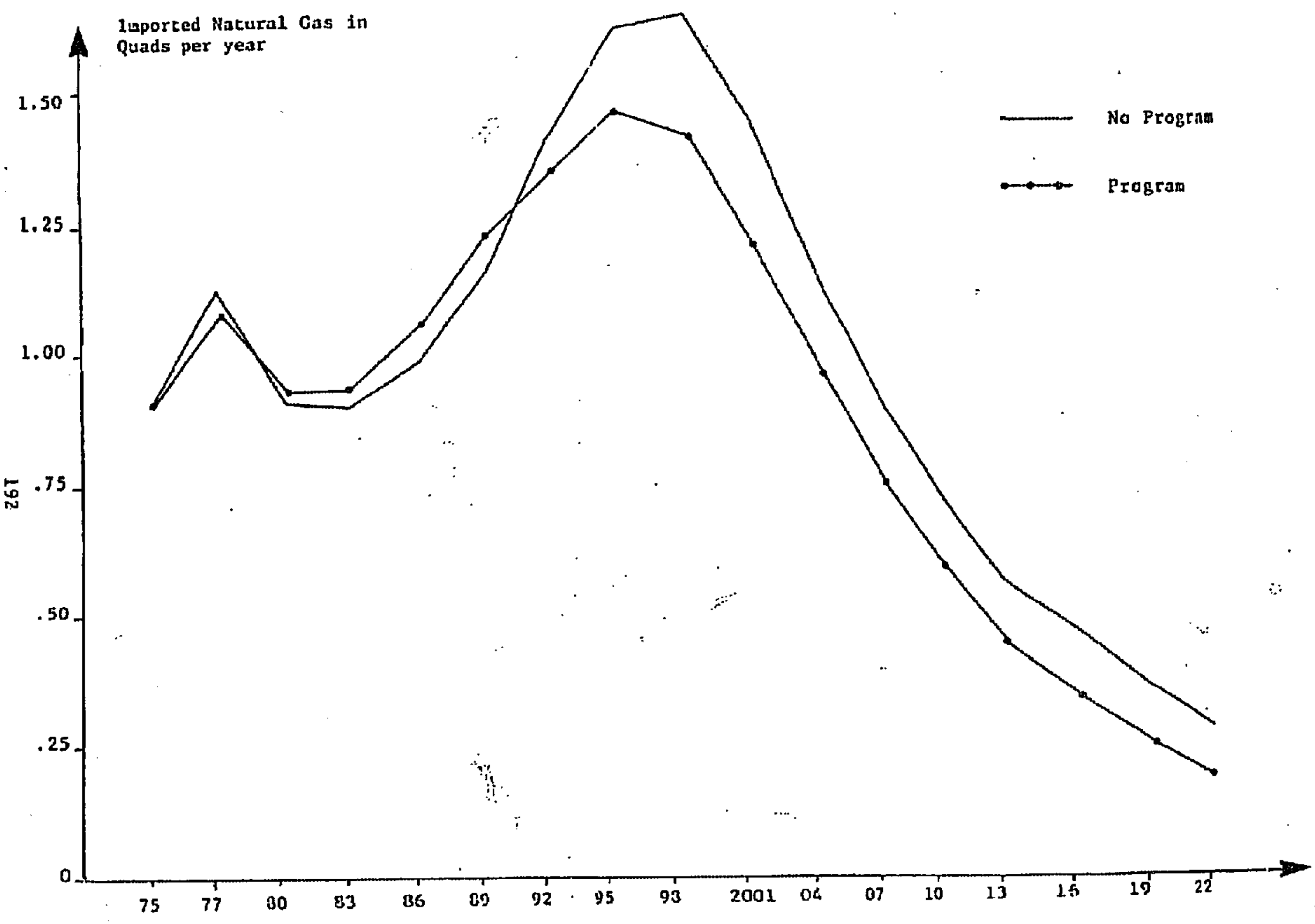
TABLE 4.50

of such an outcome surpasses the capacity of the human mind. Causal explanation of changes related to the increased attractiveness of coal-synthetic technologies is also difficult. Thus, we will present a summary figure that is more manageable. The previously discussed Figure 4.1 shows that the models produce outcomes, which are valued in dollar units by the Social Value Model. Detailed discussion of this model is contained in a following section, 4.3.0. Anticipating the reader's more complete understanding of the process, we will utilize the Social Value Model's ability to map a complex, multi-dimensional outcome into a single measure, the present value in dollars. The results of such a process are the total energy system environmental residual present value in millions of 1977 dollars:

No Program	$ 54,224 M
SNG Acceleration	54,474 M
Increase	$250 M

That is, a synthetic fuels commercialization program results in an increase in the value of environmental emissions. This result illustrates a powerful feature of the SRI National Energy Model. By considering the complex nature of interfuel competition, secondary effects in the energy markets are incorporated into the analysis; these effects can change the magnitude, and even the sign, of a result. The primary results are indicated by the residuals in the Powder River Basin and the North East Central demand region in 1994. The secondary effects are a result of supply equaling demand in all energy markets, for all regions, over the whole fifty-year time horizon. An example of such a secondary effect is shown in Figure 4.41, which depicts the imports of natural gas with and without a synthetic fuels commercialization program. The increased competitive advantage of SNG decreases the market share held by imported natural gas. This has environmental consequences. The production of SNG has residual emissions not associated with imported gas. In fact; the environmental

FIGURE 4.41



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cost of imports is zero, for that cost is borne by the foreign producing country. The sum total of all these secondary environmental effects combines with the primary results to yield the $250 million increase in environmental cost with a synthetic fuels commercialization program.

SOCIOECONOMIC EFFECTS

A detailed local socioeconomic model has been constructed for this analysis. This model was discussed in Section 4.1.3. To account for the cumulative long term effects as many plants develop in the supply regions, the local model is driven by the SRI National Energy Model. We have assumed that socioeconomic effects are negligible in the demand regions. The impact of increased population in the resource regions is included with the environmental residual results.

4.3.0 SOCIAL VALUE MODEL

At this point in the report, we have completely discussed the structural model which describes all the interactions resulting from a decision to commercialize a coal gasification technology. The form of the model is summarized in Figure 4.1, which is reproduced as Figure 4.42a. It is a synthesis of the local, short term model and the regional and national, long term SRI National Energy Model. The outcomes from these models answer the question of what happens as the result of any particular decision. To evaluate the desirability of any particular set of outcomes and hence the corresponding decision, value judgments must be applied to the outcomes. This is the purpose of the social value model. In this section, we will discuss the rationale for choosing the outcome variables and then the conceptual basis for the social value model. Finally, we will describe the specific value judgments applied to the outcomes in the base case analysis.

OUTCOMES

The outcomes represent the variables that ERDA Office of Commercialization monitors when making commercial plant selections. The particular outcomes chosen depend on how the Office of Commercialization views the purposes of its programs. In identifying outcome variables we have assumed

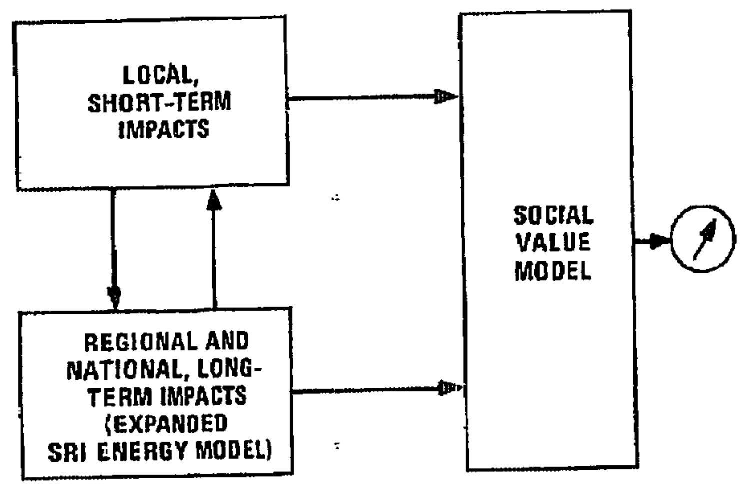


FIGURE 4.42a STRUCTURAL MODEL OF COMMERCIALIZATION

that the Office is guided by the following broadly stated goals. Programs supported by the Office of Commercialization should help to

1. Provide for the material well-being of the citizens of the United States;
2. Seek equitable resource distribution;
3. Encourage the wise use of natural resources;
4. Insure beneficial socioeconomic impacts;
5. Promote energy independence of the United States, while they
6. Minimize the cost of such programs to the government.

The outcome variables are the specific measurable quantities that describe how well programs are performing with respect to these general goals. We will briefly summarize how the variables we have previously identified fit into this framework.

MATERIAL WELL-BEING

The primary measure of material well-being is the economic cost or benefit of the program measured by the change in economic surplus. As described in the last section, economic surplus is a complex function of the quantity and price of the gas produced.

Other variables that reflect directly on the material well-being of people are whether their lives are safe and whether they have adequate shelter. Thus the amount of excess housing in the producing area and the number of deaths in the mine are important outcome variables.

EQUITABLE RESOURCE DISTRIBUTION

To measure how equitable the resource distribution is, all outcomes are calculated as a function of the region of the country affected. Thus the change in economic surplus is calculated as a function of both the producing regions and the demand regions.

WISE USE OF NATURAL RESOURCES

Environmental impacts are monitored extensively in the model. The air pollution, water pollution, land disruption, and water usage outcomes are all measures of how the natural resources are being used and how the environment is being affected by any particular decision.

SOCIOECONOMIC IMPACTS

The variables that monitor the socioeconomic impacts of gasification decisions are the excess social infrastructure, the excess social maintenance, and the population increase, all measured in the producing region. The population increase is a measure of the impact of the plant on the lifestyle of the people who would live in the area if there were no plant.

PROMOTE ENERGY INDEPENDENCE

The goal of promoting energy independence is very important for the decision of whether or not to have a synthetic fuels program. However, once the decision is made to have a program, as is the case of synthetic fuels, energy independence is no longer critical to selection between bids. Thus, in building a framework to evaluate coal gasification proposals, we have not included any outcome variables to monitor progress with respect to this goal.

COST TO GOVERNMENT

The cost of government outcome measures how well programs are performing with respect to minimizing the cost to governement.

Table 4.51 summarizes all of the outcomes that are input to the social value model. Notice that all outcomes are evaluated yearly and some are evaluated as a function of region.

PREFERENCE TRADEOFFS

On first thought, the Office of Commercialization might try to minimize all the costs and maximize all the benefits in choosing a coal gasification plant or plants to support. Unfortunately, this is physically impossible. If one were to seek to minimize environmental emissions, potentially driving them to zero, capital costs and hence economic cost would skyrocket. In this decision, as in almost all decisions, a balance must be established, tradeoffs must be made.

Preference tradeoffs express in explicit terms how much of one outcome the decision maker is willing to give up to obtain another unit of some other outcome. For example, consider the emission of SO_x by a potential

OUTCOMES:

Material Well-Being

economic cost (change in social surplus) ($/year) by region
occupational deaths (deaths/year) in producing region
excess housing (units/year) in producing region

Wise Use of Natural Resources

Air Pollution

particulates (tons/year) by region
NOx (tons/year) by region
SOx (tons/year) by region
hydrocarbons (tons/year) by region
CO (tons/year) by region
aldehydes (tons/year) by region

Water Pollution

dissolved solids (tons/year) by region
suspended solids (tons/year) by region
organics (tons/year) by region

Water Usage

usage (acre-feet/year) in producing region

Land Disruption

reclaimed land (acres) in producing region
disrupted land (acres/year) in producing region

Socioeconomic Impacts

excess social infrastructure ($/year) in producing region
excess social maintenance ($/year) in producing region
population increase (people/year) in producing region

Cost to Government

cost to federal government ($/year)

SUMMARY OF OUTCOME VARIABLES

Table 4.51

gasification plant. The tradeoff on the sulfur oxides outcome would express how much the decision maker would be willing to increase economic cost to reduce by one ton the sulfur oxides emitted. For example, the tradeoff might be given by

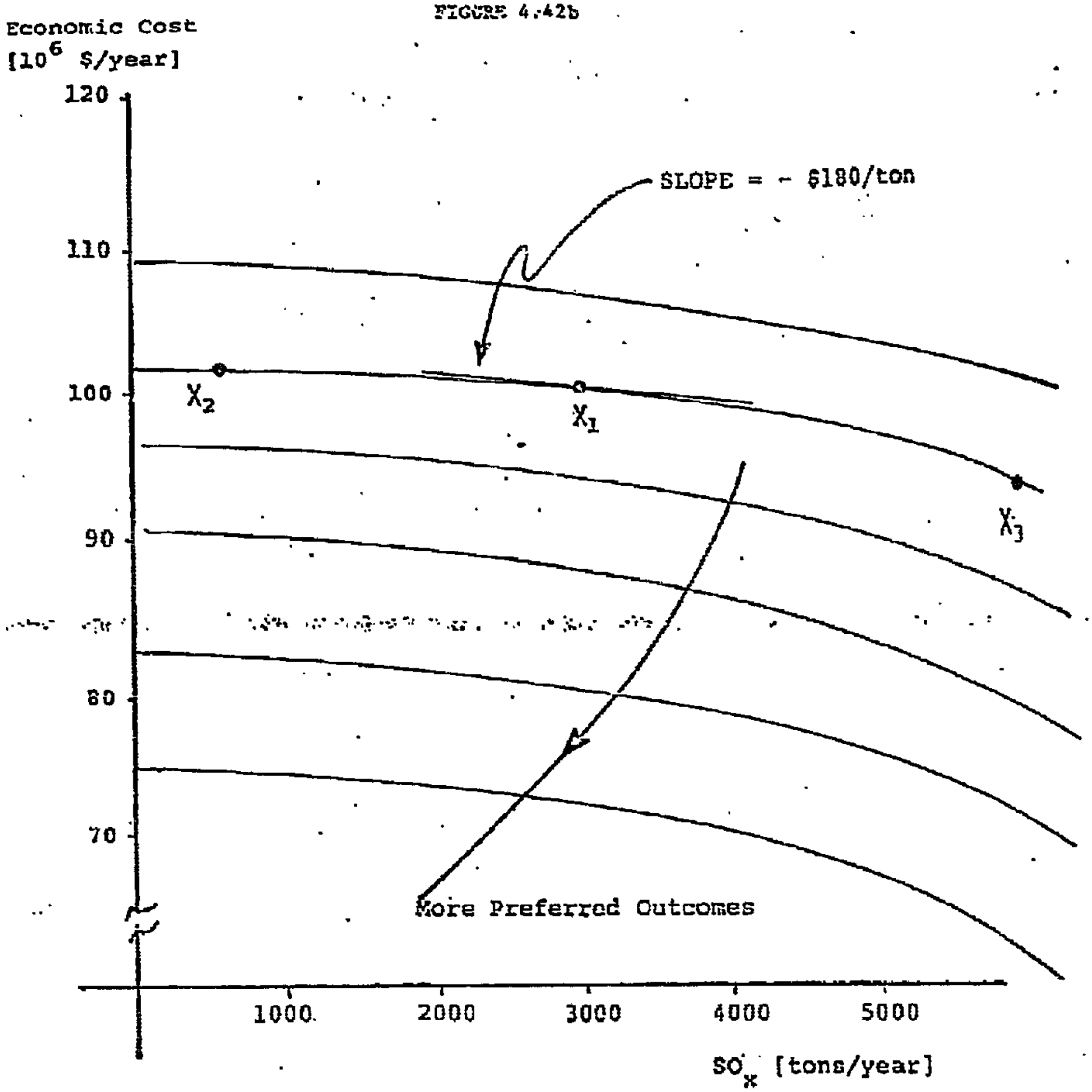
$$\text{Preference Tradeoff } (SO_x \text{ to Economic Cost}) = 180 \frac{\$}{\text{ton } SO_x}$$

which indicates that the decision maker would be willing to incur a cost of \$180.00 to reduce sulfur oxide emissions by one ton.

Conceptually, preference tradeoffs can be thought about in terms of indifference curves as shown in Figure 4.42b. Any particular combination of the two outcome variables, economic cost and sulfur oxide emissions, is a point such as X_1, (3000 ton/year SO_x, \$100 x 10^6/year cost). All the points on the same curve as X_1 are indifferent to X_1. Similarly, all points on any other indifference curve are indifferent to each other. If we think of the indifference curves as defining the contours of an indifference map, then more preferred points lie "up the preference hill" to the lower left hand corner. This merely indicates that the decision maker prefers less sulfur oxide emissions and less cost.

If a particular outcome is obtained, then the preference tradeoff is just equal to minus the slope of the indifference curve through that point. Notice that in general, the preference tradeoffs change with the outcome. At X_2 the emissions are relatively lower and the costs are relatively higher, and the preference tradeoff is smaller. Since emissions are already low, the decision maker is willing to incur less cost to reduce emissions by one ton. This change in preference tradeoff with outcome is an important factor that must be monitored; however, in evaluating any particular decision it is often not important. This is because the outcomes like SO_x emissions are measured against a background of emissions from other sources and the new emissions make only a relatively small incremental impact. Thus it is important in assessing the decision maker's preference tradeoffs to assess them with respect to a specific operating point.

FIGURE 4.42b



CONCEPTUAL INDIFFERENCE CURVES ILLUSTRATING
TRADE-OFFS OF SO_x EMISSIONS TO
ECONOMIC COST

To express the subjective values or preferences of the decision maker, we need to specify tradeoffs for each of the outcome variables. Each of these tradeoffs can be expressed in terms of a common reference outcome such as economic cost. If we have a total of N outcome variables, we have to specify (N-1) tradeoff ratios. With these tradeoffs, we can convert any set of outcome variables resulting from a particular decision to a measure of the equivalent economic cost,

Equivalent Economic Cost =

$$PT_{1N}X_1 + PT_{2N}X_2 = \cdots + PT_{N-1,N}X_{N-1} + X_N$$

where

PT_{kN} = preference tradeoff of outcome k into the reference outcome N (assumed to be economic cost)

The equivalent economic cost is a measure of the overall desirability of a particular decision reflecting the decision makers' subjective values and preferences.

PREFERENCE TRADEOFF VALUES

For evaluating the base case defined in previous sections of the report, we have assigned preference tradeoffs to each of the outcomes listed in Table 4.51. These tradeoffs do not represent assessments of ERDA personnel, but rather are SRI estimates based on the rationales described in the following paragraphs. The sensitivity of gasification decisions to changes in these tradeoffs is discussed in the next section of the report.

MATERIAL WELL-BEING

As discussed in the last section, economic cost is taken as the reference outcome so that its tradeoff is one by definition.

Based on recent work by R. A. Howard of Stanford University, a tradeoff of one million dollars is assigned to every human life lost.

Excess housing measures the units of housing that are provided over the required, or desired, figure. That is, if excess housing is -60 units, the town is 60 houses short of providing the desired level of dwelling units. There is a cost associated with excess housing when there is a housing shortage; extra houses provided produce neither costs nor benefits. Where there is a housing shortage, the preference tradeoff is given by minus ten percent times the value of a house, $25,000/house. The ten percent is made up of eight percent for the capital charge and two percent for the services associated with the capital. The eight percent assumes that a dollar of housing provides eight cents of housing value. The two percent indicates that the house provides the occupants with the opportunity to do two cents' worth of service activity for every dollar of housing.

AIR POLLUTION

The following air pollution tradeoffs are used:

Pollutant	Tradeoff in $/Ton
Particulates	20
NO_x	60
SO_x	180
Hydrocarbons	60
CO	20
Aldehydes	60

A detailed study was sponsored by the National Academy of Sciences to estimate the cost of a unit of sulfur oxides output. A plant 500 miles from a city was studied. After considering chemical reactions and weather patterns, the concentration of sulfur compounds can be calculated. Next, the total cost of the emission was calculated, including health problems, damage to materials, aesthetic costs, and the cost of acid rain. The resulting tradeoff value is used in this report. A similar study, undertaken by Stanford Research Institute, provided the preference tradeoff for the oxides of nitrogen. It was felt that the adverse effects of hydrocarbons and aldehydes are similar in magnitude to those from nitrogen oxides. Particulates and carbon monoxides were assessed as having lesser impacts. (While particulates are thought to be highly correlated with health damage, the particulates seem to require the presence of other air pollutants to cause health problems.)

WATER POLLUTION

The water pollution tradeoff values used are:

Pollutant	Tradeoff in $/Ton
Dissolved Solids	120
Suspended Solids	120
Organics	400

These tradeoffs are twice the tradeoff values for similar air pollutants. The higher value reflects the greater concentration and containment for the water medium.

WATER USAGE

The economic value of the water is included in the plant operating cost. The water used will decrease the recreational and aesthetic value of the water bodies from which it is taken. The water removed is valued at its cost for aesthetic and recreational value. It is assumed that the economic value is an upper bound, for recreational users and viewers could purchase the water on the open market and replace it if desired. The economic value is $200 per acre-foot.

LAND DISRUPTION

There are two classes of costs and benefits associated with land disruption. First, the disrupted land is not considered aesthetically pleasant and a tradeoff of $1,000 per acre is assumed. Second, the land disrupted could be used in productive activity. After the land is reclaimed, it will again be able to sustain agricultural activity, which can be of greater or lesser productivity. The agricultural opportunity cost is $100 per acre before reclamation. After reclamation, the land is slightly more productive, with a productive value of $120 per acre.

SOCIOECONOMIC IMPACTS

The excess social infrastructure is handled in a similar manner to the excess housing. The tradeoff on the excess infrastructure is minus fifteen percent. The fifteen percent is made up of ten percent of capital

PREFERENCE TRADEOFFS:	OUTCOMES:
	Material Well-Being
1	economic cost (change in social surplus) ($/year) by region
$1,000,000/death	occupational deaths (deaths/year) in producing region
-$2,500/unit	excess housing (units/year) in producing region
	Wise Use of Natural Resources
	Air Pollution
$20/ton	particulates (tons/year) by region
$60/ton	NOx (tons/year) by region
$180/ton	SOx (tons/year) by region
$60/ton	hydrocarbons (tons/year) by region
$20/ton	CO (tons/year) by region
$60/ton	aldehydes (tons/year) by region
	Water Pollution
$120/ton	dissolved solids (tons/year) by region
$120/ton	suspended solids (tons/year) by region
$400/ton	organics (tons/year) by region
	Water Usage
$200/acre-foot	usage (acre-feet/year) in producing region
	Land Disruption
-$20/acre	reclaimed land (acres) in producing region
$1100/acre	disrupted land (acres/year) in producing region
	Socioeconomic Impacts
$-.15/$	excess social infrastructure ($/year) in producing region
$-1/$	excess social maintenance ($/year) in producing region
$500/person	population increase (people/year) in producing region
	Cost to Government
$1/$	cost to federal government ($/year)

SUMMARY OF VALUES OF PREFERENCE TRADEOFFS

TABLE 4.52

charge, and five percent of services that would be associated with the capital. The tradeoff on excess maintenance is minus one. This just means that a dollar shortfall in maintaining the social infrastructure is equivalent to a dollar of economic cost.

The preference tradeoff assigned to the population increase in the producing region is $500 per person. This represents the "change in lifestyle" cost incurred by the introduction of the plant. The cost of every person introduced into the producing region who would not have been there without the plant is $500 per person.

COST TO GOVERNMENT

The numerous categories of cost to government -- excluding government transfer payments -- are summed to yield a yearly dollar figure. The preference tradeoff on this figure is one, indicating that a dollar of government cost is valued at the equivalent of a dollar of economic cost. Transfer payments are excluded since they represent transfers of funds between members of society and are thus not a net cost or benefit.

TIME PREFERENCE

The above tradeoffs allow the calculation of a dollar cost or benefit for each year of the gasification project. In order to take into account time preference, also called the time value of money, the dollar flows are discounted to provide a discounted present value. The discount rate used in ten percent, reflecting direction from the Office of Management and The Budget.

Table 4.52 is a summary of the preference tradeoffs assigned to each outcome variable. At present there is no differentiation in the tradeoffs assigned to the different regional outcomes.

4.4.0 SUMMARY DISCUSSION OF THE BASE CASE

Each previous part of Section 4 has discussed in detail an aspect of the bid evaluation framework. The discussion of each topic has included the assumptions, the results, and some important sensitivities. This section will summarize the preceding. There are three parts:

1. The major assumptions
2. Summary of the outcomes
3. Summary of the valued outcomes

4.4.1 MAJOR ASSUMPTIONS

The major assumptions defining the base case are best understood when viewing the decision tree structuring this analysis, Figure 3.2, reproduced as Figure 4.43. Node 1 shows the bid acceptance decision of ERDA; we assume that a 250MM Scf/stream day Lurgi plant is built. Node 2 shows the first plant outcomes; we assume that the first Lurgi plant is a success and produces gas at an average price of $3.18/Mcf. While it is possible to conceive of a lower cost plant, the potential is probably greater for increased cost of gas. Nodes 3 and 4 show that the first plant produces knowledge about first and second generation coal gasification; we assume significant learning on first generation production methods. The 1985 import price uncertainty is represented by Node 5; we assume that the OPEC cartel is strong, and that a high price for imported oil provides a strong economic incentive for domestic energy production. Nodes 6, 7, and 8 show the reactions of the government regulators, the financial community, and the utility industry; we assume that these groups act so as not to inhibit the growth of a large SNG industry. Nodes 9 and 10 represent the conditions in the markets for energy when a coal gasification industry could be in place; we assume that these markets, including the status of the OPEC cartel, are favorable to a synthetics industry. These general assumptions are complemented by the detailed assumptions contained in the previous parts of Section 4. Remember that this is just one of the possible paths through the decision tree; actual policy decisions would have to be based on the likelihood and consequences of taking many similar paths.

4.4.2 BASE CASE OUTCOME SUMMARY

The first commercial Lurgi plant produces a trajectory of gas prices over time, contained in Table 4.24, and reproduced as Table 4.53. These gas prices are high in relation to those of competing gas supplies, and this difference causes a loss of $526 million in consumer surplus because

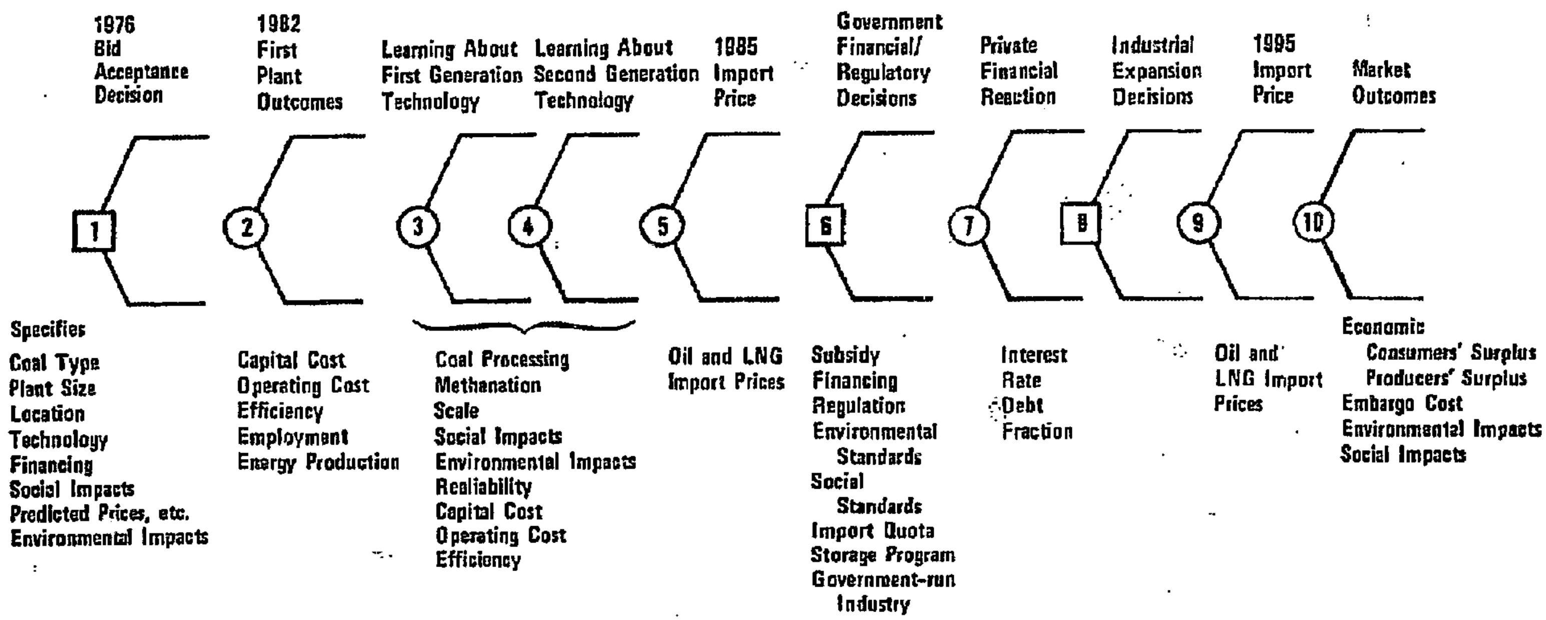


FIGURE 4.43 DECISION TREE

of the first commercial plant. The plant is built in a remote area. The base case town has 5000 citizens before the plant is built. The gasification activity disrupts the local community, creating an increase in population and shortages of social services and housing. This is shown in Figure 4.19, reproduced as Figure 4.44. The plant causes an increase in environmental residuals in the local area; the yearly emissions at full stream factor are shown in Table 4.54. The government incurs minor costs because of the first commercial Lurgi plant. The yearly amounts are listed in Table 4.32, reproduced as Table 4.55.

The commercialization program has two major long term outcomes. The availability of first generation gasification technology is accelerated by five years, from 1990 to 1985. The second generation methods are accelerated from 1992 to 1989. This increases the amount of SNG utilized in the energy markets. The quantities are listed in Table 4.56. This can be translated into an increase in economic surplus of $1.1 billion. There is also a change in the long run quantities of environmental residuals. While the exact change is a complicated function of region and time, the general direction is that the program increases residuals marginally, as relatively polluting synthetic gas production replaces other energy sources in the marketplace for energy.

4.4.3 BASE CASE OUTCOME VALUATION

The social value model has been used to map the base case outcomes into a present value of the outcome. Table 4.57 lists the summary of the base case values. When attempting to understand the coal gasification bid evaluation decision, the relative size of each component provides major insights, indicating the important impacted areas. The magnitude and sign of the total depends on the assumptions used, and the value tradeoffs assigned. However, reasonable changes in the value tradeoffs have no effect on the sensitivities that we have discussed.

Commercialization is a $245 million net producer of benefits under the favorable assumptions of the base case. The major determinants of

GAS PRICE
INFLATION EFFECTS INCLUDED
1975 $

YEAR	PRICE
1	7.31
2	7.74
3	4.23
4	4.07
5	3.92
6	3.78
7	3.65
8	3.53
9	3.41
10	3.30
11	3.20
12	3.11
13	3.02
14	2.94
15	2.86
16	2.79
17	2.72
18	2.65
19	2.59
20	2.51
21	2.41
22	2.32
23	2.23
24	2.16
25	2.08

AVERAGE PRICE - 3.18

TABLE 4.53

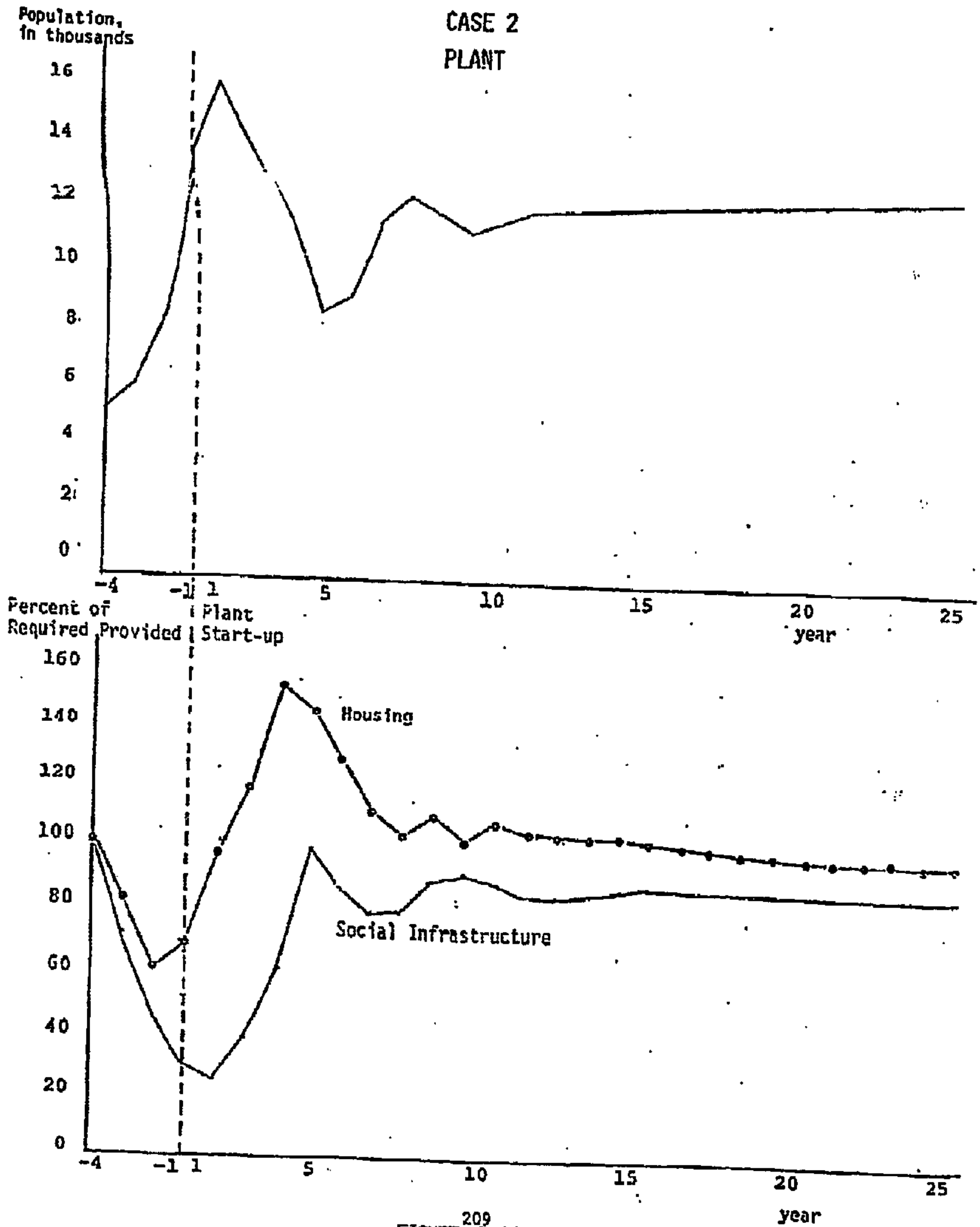

CASE 2
PLANT
Population, in thousands
16
14
12
10
8
6
4
2
0
-4
-1
1
5
10
15
20
25
year
Plant Start-up
Percent of Required Provided
160
140
120
100
80
60
40
20
0
Housing
Social Infrastructure
-4
-1
1
5
10
15
20
25
year

FIGURE 4.44

YEARLY Environmental Emissions from First Lurgi Plant

Residual	Emission, in Tons
Air	
Particulates	602
Nitrogen Oxides	6,152
Sulfur Oxides	32
Hydrocarbons	113
Carbon Monoxide	415
Aldehydes	39
Water	
Dissolved Solids	3,540
Suspended Solids	74
Organics	35

TABLE 4.54

COST TO GOVERNMENT

YEAR	LABOR	TRANSFER PAYMENT COST, $M	ADMINISTRATIVE COST, $M	TOTAL COST $M
-4	300	(.14)	2.00	1.86
-3	1400	(.66)	2.00	1.34
-2	3400	(1.60)	2.00	.40
-1	3700	(1.74)	2.00	.26
1	2300	(1.08)	.50	(.58)
2	1900	(.89)	.50	(.39)
3 To 25	1400	(.66)	.50	(.16)

FIGURE 4.55

this number are the economic factors. The first Lurgi plant economic outcome is the major source of cost ($526M), while the long run economic benefits of accelerated technology availability provides the major benefit ($1,100M). The long run cost of environmental residuals is significant ($250M), but the environmental impact of the first commercial Lurgi plant ($27M) is within the noise level of the large numbers. While the socioeconomic cost of the first plant is not too large ($52M), its concentration on a small number of people increases its importance.

PRICES AND QUANTITIES OF SNG

	BASE CASE		EARLY SNG	
	PRODUCTION (QBTU/YR)	PRICE ($/MMBTU)	PRODUCTION (QBTU/YR)	PRICE ($/MMBTU)
1986	0	-	.078	2.81
1989	0	4.00	.235	3.08
1992	.673	2.82	1.975	2.63
1995	.897	2.95	3.306	2.61
1998	2.455	2.72	4.842	2.60
2001	5.592	2.60	6.938	2.58
2004	9.569	2.52	10.554	2.51
2007	13.663	2.47	14.412	2.49
2010	17.941	2.42	18.110	2.48
2013	21.611	2.41	21.715	2.45
2016	24.814	2.43	25.422	2.43
2019	27.454	2.44	28.672	2.42
2022	29.895	2.46	31.184	2.45

TABLE 4.56

PRESENT SOCIAL VALUE OF THE BASE CASE

		$ Millions	
		Costs	Benefits
Cost of the First Lurgi Plant			
Economic Surplus		526	
Environmental Costs			
Occupational Deaths	2		
Air Pollution	6		
Water Pollution	2		
Water Aesthetic	12		
Land Disruption	5		
Total Environmental		27	
Socioeconomic Costs			
Service Shortages	28		
Change in Lifestyle	24		
Total Socioeconomic		52	
Total Cost of First Lurgi Plant		605	0
Long Run Effects			
Economic Surplus			
Consumers' Surplus			2,300
Producers' Surplus		1,200	
Net			1,100
Environmental Residuals		250	
Total		855	1,100
Net			245

TABLE 4.57

SUMMARY OF INFORMATION REQUIRED FOR EVALUATION OF COAL GASIFICATION COMMERCIALIZATION PROPOSALS

The previous sections develop a framework for evaluating coal gasification commercialization proposals. Thus, the information that respondents to a request for proposal should furnish ERDA to utilize the framework is defined. Our intention is not in any way to outline the document itself, but rather to communicate what we think some of its essential contents should be. From the bid evaluation perspective, it is important to communicate two categories of information to potential bidders:

1. The basis for the evaluation of proposals, and
2. The information that bidders are required to submit.

We will discuss these two categories in the following sections.

5.1 BASIS FOR EVALUATION

Bidders should be clearly informed that their proposals will be evaluated in terms of their impact on the following variables which are grouped according to type of effects measured:

Economic Impacts

Price of gas produced

Quantity of gas produced

Distribution of gas produced

Environmental Impacts

Air Pollution:

Particulates

NO_x

SO_x

Hydrocarbons

Aldehydes

CO

Water Pollution:

Dissolved solids

Suspended solids

Organics

Water Usage:

Water usage per year

Land Disruption:

Disrupted land

Reclaimed land

<u>Socioeconomic Impacts</u>

Housing supply in producing region

Social infrastructure in producing region

Maintenance of social infrastructure in producing region

Population in producing region

<u>Cost to Government</u>

Cost to the federal government

These variables are essentially the outcomes that we have identified in Section 4. The only change in the present list is that we have identified the economic variables -- price, quantity, and distribution of gas -- that we use to calculate change in economic surplus, rather than listing economic surplus directly.

5.2 INFORMATION REQUIRED FROM BIDDERS

In general, potential bidders should be required to supply all information that my be necessary to determine the impacts of their proposals on the variables listed in the previous section. In particular, bidders are required to supply the following:

<u>Economic Impacts</u>

Price of gas produced:

1. coal cost
2. operating cost, including:
   a) labor
   b) supplies
   c) maintenance
   d) property taxes
   e) etc.

3. capital cost, including:
    a) debugging required to reach nameplate capacity
    b) recurring capital
4. cost of pipelining gas to market

All of the above should be supported by summary engineering data:

Quantity of gas produced:

1. per stream day, supported by summary engineering data
2. assumed stream factor, including start-up

Distribution of gas produced:

1. the geographic area
2. the number of customers
3. the anticipated gas supply/demand picture in the region

Environmental Impacts

Air Pollution:

1. the air pollutants emitted per stream day

Water Pollution:

1. the water pollutants emitted per stream day, broken down by
    a) surface discharge
    b) deepwater discharge

Water Usage:

1. acre-feet per year as a function of
    a) mine production
    b) plant production

Land Disruption:

1. acres of land disrupted by mining
2. acres of land utilized by permanent facilities
3. use value of the land before mining
4. use value of the land after reclamation

Socioeconomic Impacts

1. the construction labor force
2. the fraction of the construction labor force imported from outside the producing region
3. the operating labor force
4. the fraction of the operating labor force imported from outside the producing region
5. the number of living units provided by bidder
6. financing offered to producing region, including payback requirements

The information outlined above is what is required from the bidders to apply the evaluation framework.

Appendix A

EQUATIONS FOR SOCIOECONOMIC MODEL

APPENDIX A

Equations for Socioeconomic Model

This appendix contains the equations defining the socioeconomic model. In the equations t is measured in years. Initial conditions, parameter values, and functions that must be provided by the user are written in the form:

Pop_Growth = ________________

In other words, the user must "fill in the blank" and specify the rate of growth of population. The functions that we have used in defining the base case town are shown in Figures A-1 - A-4 after the equations. Coupled with the prose description in the text, the equations should be self-explanatory.

POPULATION SUBMODEL

Population (t) = (1 + Pop_Growth) * Population (t-1) + Immigration (t-1)

Pop_Growth = ________

Population (0) = ________

Immigration (t) = Fraction_Construction_Outside * (Construction_Labor (t) - Construction_Labor (t-1)) * Ave_No_People_Per_Construction_Worker

+ Fraction_Operating_Outside * (Operating_Labor (t) - Operating_Labor (t-1)) * Ave_No_People_Per_Operating_Worker

+ Immigration_Rate (t-1) * Population (t-1)

Fraction_Construction_Outside = ________

Construction_Labor (t) = ________

Ave_No_People_Per_Construction_Worker = ________

Fraction_Operating_Outside = ________

Operating_Labor (t) = ________

Ave_No_People_Per_Operating_Worker = ________

$$\text{Immigration\_Rate (t)} = \text{Function}\left(\frac{\text{Unemployment\_Rate (t)}}{\text{Regional\_Unemp\_Rate}} * \text{Social\_Services\_Multiplier (t)}\right)$$

= ________

Labor_Force (t) = Frac_Pop_Working * Population (t)

$$\text{Social\_Services\_Multiplier (t)} = \text{Function}\left(\frac{\text{Social\_Infrastruc\_Provided (t-1)}}{\text{Social\_Infrastruc\_Required (t-1)}}\right)$$

= ________

Regional_Unemp_Rate = ________

Frac_Pop_Working = ________

LOCAL ECONOMY SUBMODEL

Total_Jobs (t) = Plant_Jobs (t)
+ Retail_Jobs (t)
+ Other_Jobs
+ Gov_Jobs (t)

Plant_Jobs (t) = Construction_Jobs (t)
+ Operating_Jobs (t)

$$\text{Gov\_Jobs (t)} = \frac{\text{Social\_Investment\_Made (t)}}{\text{Ave\_No\_Investment\_\$\_Per\_Worker}} + \frac{\text{Social\_Maintenance\_Provided (t)}}{\text{Ave\_No\_Maintenance\_\$\_Per\_Worker}}$$

Ave_No_Investment_$_Per_Worker = __________

Ave_No_Maintenance_$_Per_Worker = __________

$$\text{Retail\_Jobs (t)} = \frac{\text{Retail\_Business (t)}}{\text{Retail\_Sales\_Per\_Employee}}$$

Retail_Sales_Per_Employee = __________

Retail_Business (t) = Population (t) * Ave_Spending_Per_Person

Ave_Spending_Per_Person = __________

Other_Jobs (t) = (1 + Job_Growth_Rate) * Other_Jobs (t-1)

Job_Growth_Rate = __________

Other_Jobs (0) = __________

Construction_Jobs (t) = __________

Operating_Jobs (t) = __________

$$\text{Unemployment\_Rate (t)} = \frac{\text{Labor\_Force (t)} - \text{Total\_Jobs (t)}}{\text{Labor\_Force (t)}}$$

HOUSING SUBMODEL

$$\text{Housing\_Required}(t) = \frac{\text{Population}(t)}{\text{Ave\_People\_Per\_House}}$$

Ave_People_Per_House = ________

Existing_Housing (t) = Existing_Housing (t-1)

+ Exogenous_Housing (t)

+ Housing_Change (t-1)

If Housing_Required (t) > Existing_Housing (t)

Then $$\text{Housing\_Change}(t) = \frac{\text{Housing\_Required}(t) - \text{Existing\_Housing}(t)}{\text{Housing\_Construction\_Delay}}$$

Else $$\text{Housing\_Change}(t) = \frac{\text{Housing\_Required}(t) - \text{Existing\_Housing}(t)}{\text{Housing\_Destruction\_Delay}}$$

Existing_Housing (0) = ________

Exogenous_Housing (t) = ________

Housing_Construction_Delay = ________

Housing_Destruction_Delay = ________

$$\text{Indicated\_Tax\_Rate}(t) = \text{Function}\left(\frac{\text{Gov\_Revenue\_Required}(t)}{\text{Gov\_Revenue\_Available}(t)}\right)$$

= ________

Tax_Rate (t) = Rax_Rate (t-1)

$$+ \frac{\text{Indicated\_Tax\_Rate}(t-1) - \text{Tax\_Rate}(t-1)}{\text{Tax\_Adj\_Time}}$$

Tax_Rate (0) = ________

Tax_Adj_Time = ________

Tax_Revenue (t) = Tax Rate (t) * Property_Value (t)

+ Retail_Sales_Fraction * Retail_Sales (t)

Retail_Sales_Fraction = ________

$$\text{Indicated\_Property\_Value\_Inflation\_Rate}(t) = \text{Function}\left(\frac{\text{Housing\_Required}(t)}{\text{Existing\_Housing}(t)}\right)$$

= ________

HOUSING SUBMODEL (Continued)

$$\text{Property\_Value\_Inflation\_Rate (t)} = \text{Property\_Value\_Inflation\_Rate (t-1)} + \frac{\text{(Indicated\_Property\_Value\_Inflation\_Rate (t-1)} - \text{Property\_Value\_Inflation\_Rate (t-1))}}{\text{Property\_Value\_Adj\_Time}}$$

Property_Value_Adj_Time = ________

Property_Value (t) = Existing_Housing (t-1) * Nom_Val_Per_House
+ Property_Value_Inflation_Rate (t-1) * Existing_Housing (t-1)
* Nom_Val_Per_House
+ Plant_Value (t)

Plant_Value (t) = ________

SOCIAL SERVICES SUBMODEL

Social_Infrastruc_Required (t) = Population (t) * Social_Infrastruc_Per_Person

Social_Infrastruc_Per_Person = ________

Social_Maintenance_Required (t) = Social_Infrastruc_Provided (t) * Maintenance_Cost_Fraction

+ Out_Front_Repayment (t)

+ Bond_Repayment (t)

Maintenance_Cost_Fraction + ________

Out_Front_Repayment (t) = ________

Bond_Repayment (t) = ________

<u>If</u> Gov_Revenue_Available (t) > Social_Maintenance_Required (t)

<u>Then</u> Social_Maintenance_Provided (t) = Social_Maintenance_Required (t)

Remaining_Gov_Revenue (t) = Gov_Revenue_Available (t)

− Social_Maintenance_Provided (t)

Social_Infrastruc_Provided (t) = Social_Infrastruc_Provided (t-1)
* (1 − Social_Depreciation (t-1))

+ Social_Investment_Made (t-1)

Social_Infrastruc_Provided (0) = ________

Social_Depreciation (t) = Nominal_Depreciation

$$+ \frac{\text{Social\_Maintenance\_Required (t-1) Social\_Maintenance\_Provided (t-1)}}{\text{Non\_Maintenance\_Depreciation * Social\_Maintenance\_Required}}$$

Nominal_Depreciation = ________

Non_Maintenance_Depreciation = ________

<u>If</u> Remaining_Gov_Revenue (t) > Social_Infrastruc_Required (t)

− Social_Infrastruc_Provided (t)

<u>Then</u>

$$\text{Social\_Investment\_Made (t)} = \frac{\text{Social\_Infrastruc\_Required − Social\_Infrastruc\_Provided (t)}}{\text{Social\_Investment\_Delay}}$$

Social_Investment_Delay = ________

<u>Else</u>

$$\text{Social Investment Made (t)} = \frac{\text{Remaining\_Gov\_Revenue (t)}}{\text{Social\_Investment\_Delay}}$$

SOCIAL SERVICES SUBMODEL (Continued)

<u>Else</u>

Social_Maintenance_Provided (t) = Gov_Revenue_Available

Social_ Infrastruc_Provided (t) = Social_ Infrastruc_Provided (t-1)
* (1 - Social_Depreciation (t))

Social_Depreciation (t) = Nominal Depreciation

$$+ \frac{\text{Social\_Maintenance\_Required } (t-1) \text{ Social\_Maintenance\_Provided } (t-1)}{\text{Non\_Maintenance\_Depreciation } * \text{ Social\_Maintenance\_Required}}$$

LOCAL GOVERNMENT REVENUE SUBMODEL

Gov_Revenue_Required (t) = Social_Infrastruc_Required (t)
- Social_Infrastruc_Provided (t)
+ Social_Maintenance_Required (t)

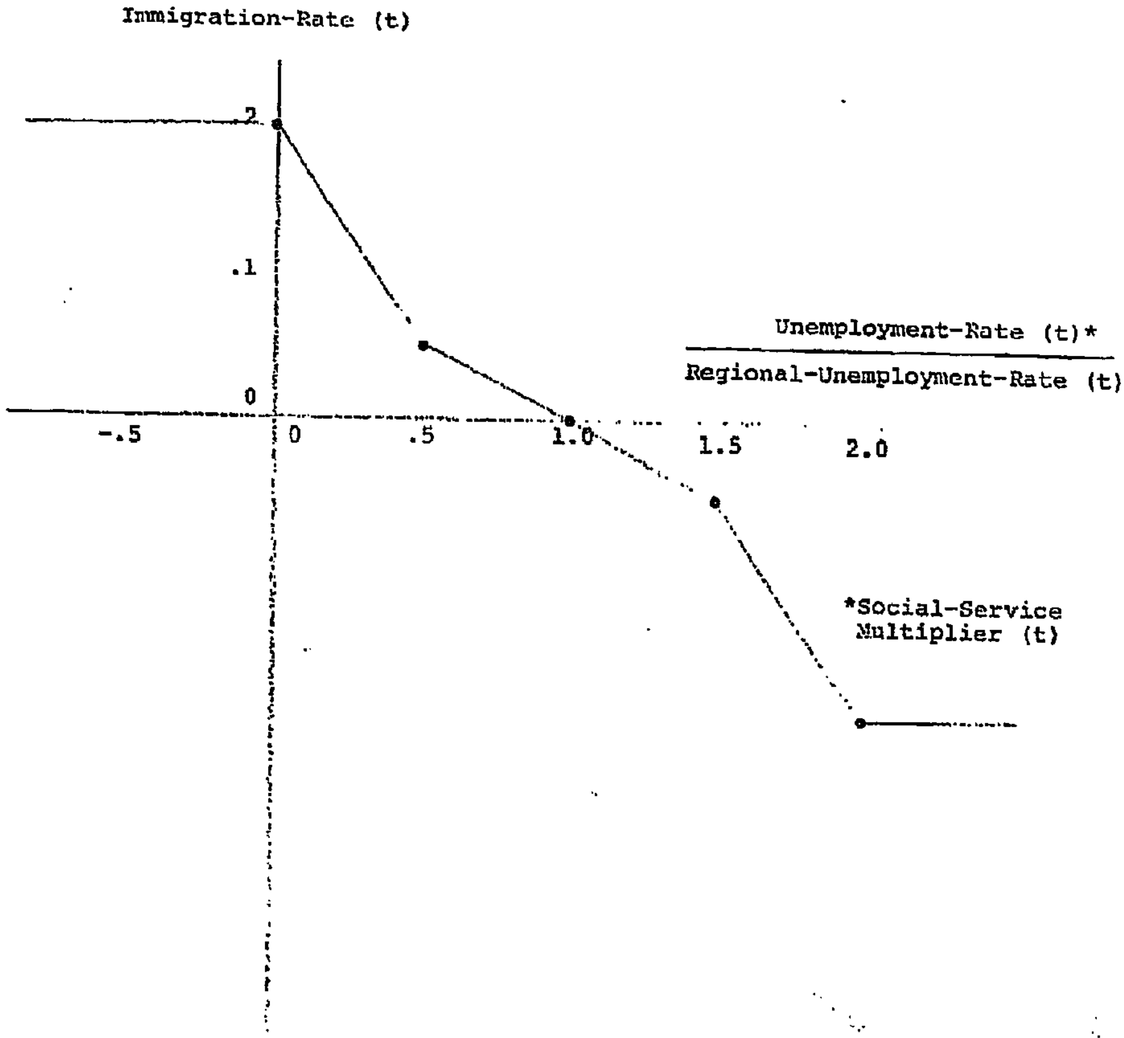
Gov_Revenue_Available (t) = Gov_Revenue_Available (t-1)
+ Tax_Revenue (t)
+ Bond_Revenue (t)
+ Intergovernmental_Transfers (t)

Out_Front_Money (t) = __________

Bond_Revenue (t) = __________

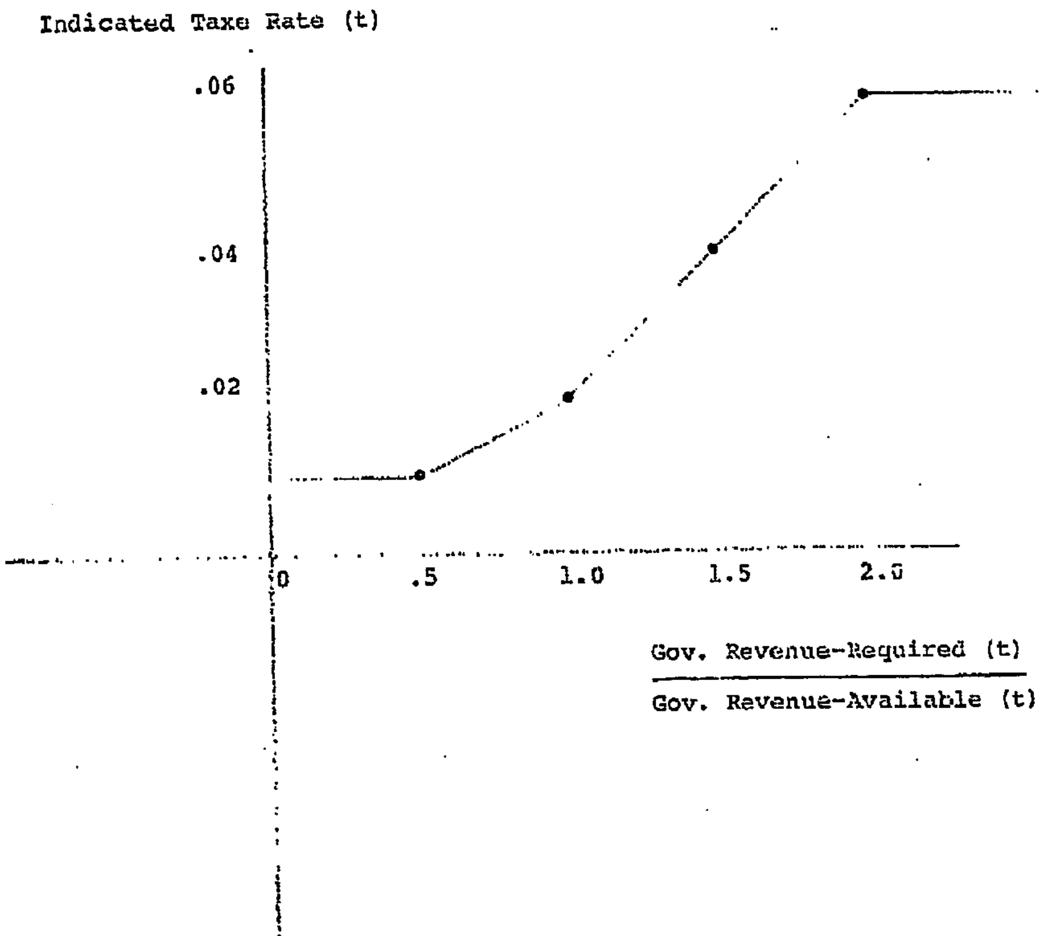
Intergovernmental_Transfers (t) = __________

Gov_Revenue_Available (o)= ________________



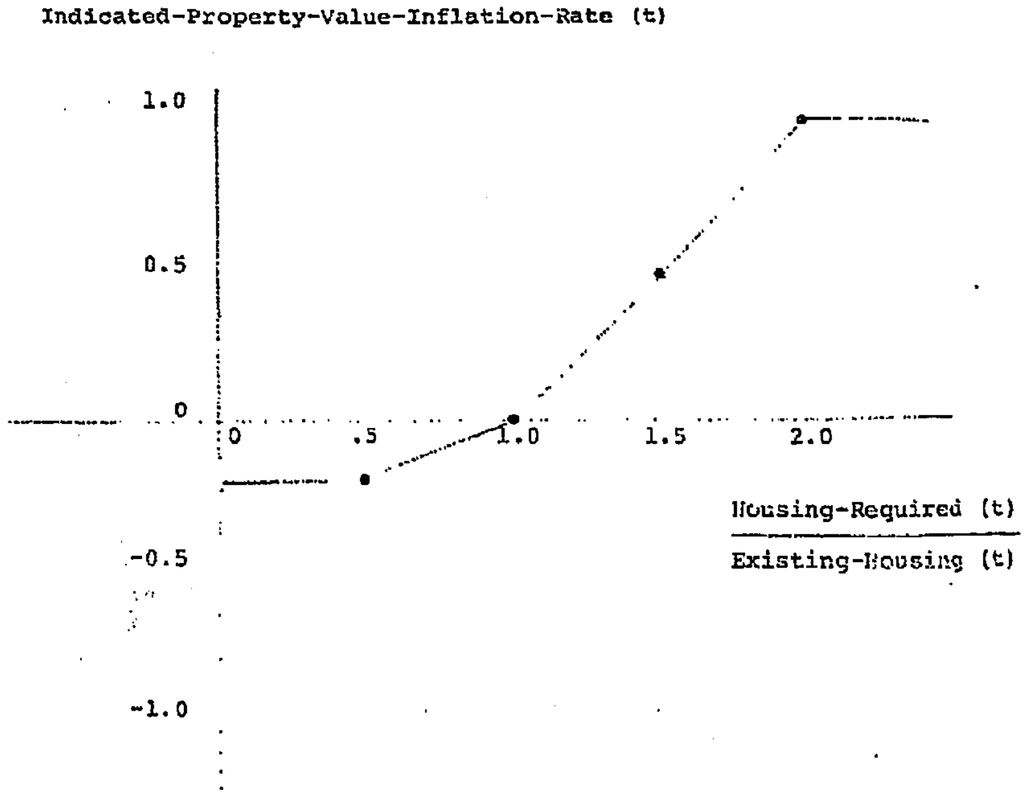
IMMIGRATION RATE

Figure A-1



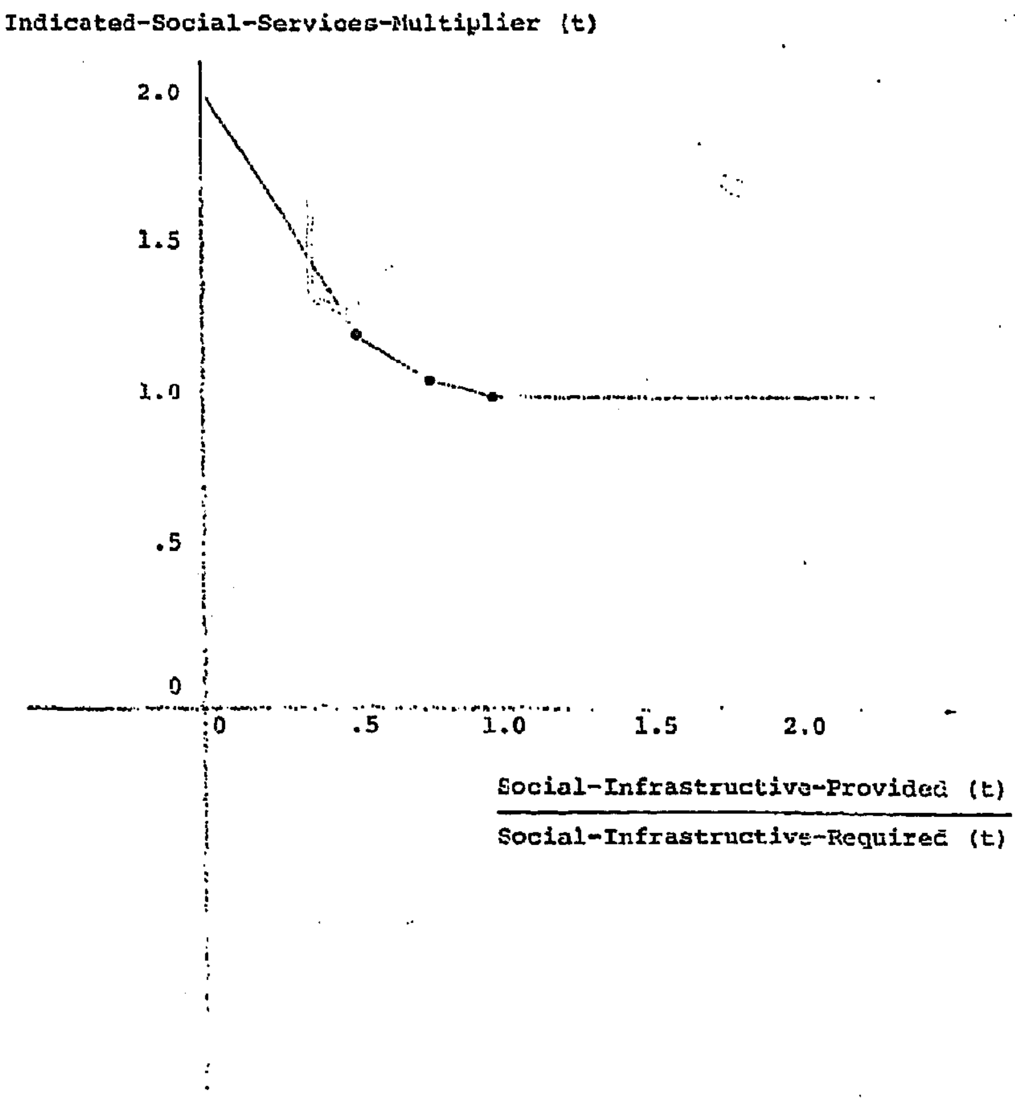
INDICATED TAX RATE

Figure A-2



INDICATED PROPERTY VALUE INFLATION RATE

Figure A-3



INDICATED SOCIAL SERVICES MULTIPLIER

Figure A-4

Appendix B

SRI ENERGY MODEL

APPENDIX B

SRI ENERGY MODEL

I INTRODUCTION

An energy model should be a decision-making tool designed to help those who make or recommend energy-related decisions. Because of the complexity of energy-related decisions a single energy model cannot be accurate or useful for broad classes of such decisions. An energy model must be focused on specific decisions so that the sensitivity of a decision to important assumptions can be checked. For these reasons, it is important that those who use or criticize the output of an energy model understand the methodology used in its construction.

This paper describes an energy modeling methodology that can be used in evaluating decisions affected by projections of future energy prices and quantities. First, the need for an energy model is illustrated by a specific application at Gulf Oil Corporation. Typical outputs from the model used in the Gulf study are used to indicate the scope and detail that can be achieved in an energy model developed by this methodology. In Section II, the features required in an energy model are discussed. Section III discusses the basic, computational concepts of the methodology, and Section IV discusses the applications.

The Gulf Synthetic Fuels Decision

During 1973 and 1974, SRI worked with Gulf to perform a decision analysis of alternatives for producing synthetic fuels. One of the important alternatives facing Gulf was whether to participate in potential coal gasification ventures in the Powder River Basin (Montana and Wyoming). Such an undertaking would require investments in a gasification plant costing approximately $0.5 billion, new coal mines, and a pipeline to deliver pipeline-quality synthetic gas to Chicago or other distant markets. This gas would compete there with natural or synthetic gas from other sources.

At the beginning of the decision analysis, intuitive arguments and conventional profit analyses demonstrated that the profitability of a gasification venture would be determined essentially by the future prices of pipeline quality gas in markets such as Chicago and the prices of coal in the Powder River Basin. The projections of these prices over the thirty- to forty-year construction and operating life of a gasification plant were highly uncertain. Although the technical and other business aspects of the venture were of concern, the major determinants of the venture's profitability – and hence the strategic decision to build or not – were the projections of future prices of gas and coal.

In 1973, the future price projections for gas were very confused because of uncertain government regulatory policy and uncertain natural gas supplies and consumption. Many energy specialists were forecasting a gap between the quantities of gas that consumers would buy at the projected prices and the quantities that would be produced at the projected prices. Some specialists argued that this gap provided an attractive market for synthetic gas. Their projected prices of gas, however, were considerably below the prices required for a profitable coal gasification venture. Clearly, the prices of gas would have to increase in order to bring supply and demand into balance; but when the prices would be high enough to justify production of synthetic gas was the important question to be resolved.

As a result of the confusion in future price projections for gas, the projections of future prices had to be built from more basic information on natural gas resources and the effect of higher prices on natural gas production. Similar information was required on other energy resources, as well as economic and technical information on energy use, conversion, transportation, and information on government regulatory policy. This additional information was required because interfuel competition in several markets geographically distant from each other and evolving over time has a major effect on the prices of coal and gas.

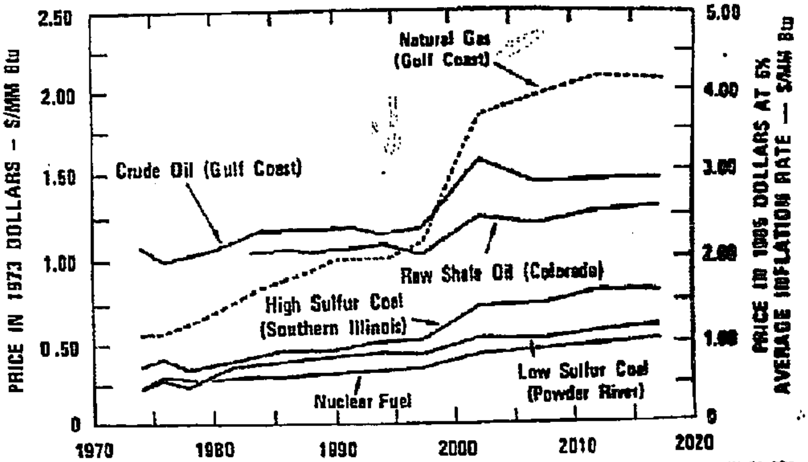
Synthesizing the basic information necessary for projecting prices requires a comprehensive dynamic model of energy supply, demand and pricing. Simple models or hand calculations cannot cope with the necessary detail. The scope and detail of the model that was developed in the Gulf study are discussed below.

Model Output

Figures 1 through 3 are typical of the output generated by the model used in the SRI-Gulf decision analysis. Figures 1 and 2 show the prices and quantities that represent a dynamic supply and demand balance for the United States, and Figure 3 gives some of the underlying detail in the price and quantity forecasts.

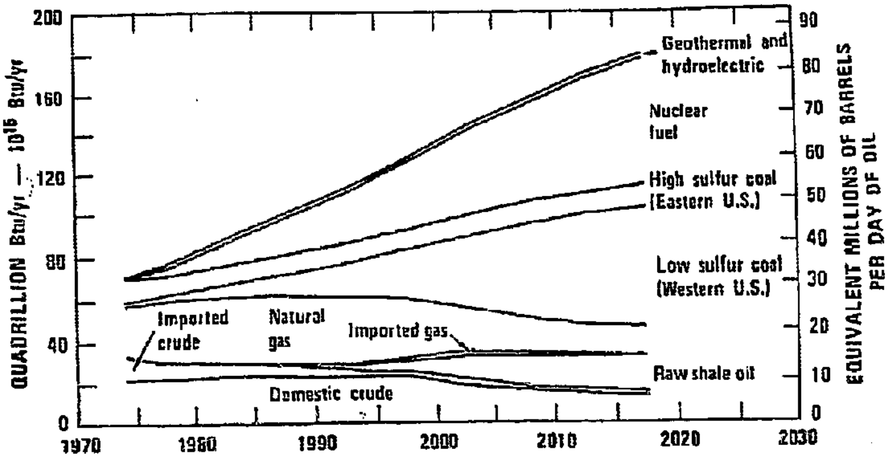
In Figure 1, the prices of primary resources are shown to increase as those resources are depleted. (Note that the prices are expressed in constant dollars.) The price projection for natural gas is of most interest. In the near term, natural gas is attractively priced relative to other fuels and its usage increases. (The nominal case assumes no regulation of natural gas prices.) As the less expensive sources of natural gas are depleted, the price of gas increases. Eventually, the use of gas begins to decline as other, more economic fuels are substituted for gas in industrial and power generation markets. Finally, beyond about 2005, the price of natural gas rises to a level that is set by the price of synthetic gas from coal. The rate at which the price of natural gas increases is of great importance in determining the timing and profitability of a coal gasification venture.

Figure 2 shows that as the prices of conventional sources such as crude oil, natural gas, and high sulfur (Eastern) coal increase, newer forms of energy such as nuclear, shale oil and low sulfur (Western)



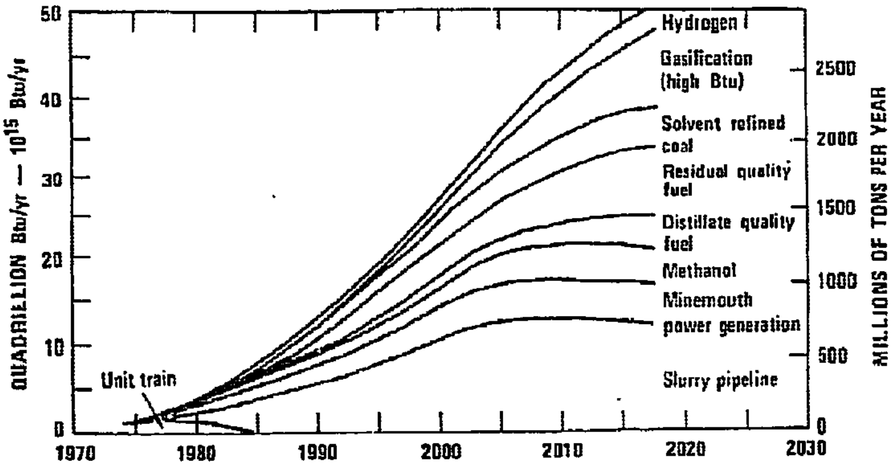
NOTE: Prices shown here are wellhead or minemouth prices and do not include transportation costs or any new taxes applied after 1974. The price of nuclear fuel includes enrichment costs

FIGURE 1 PRICES OF PRIMARY RESOURCES (CONSTANT DOLLARS): NOMINAL CASE



NOTE: These figures are representative only of the model output and should not be regarded as official projections of SRI or any of SRI's clients since they may be sensitive to input assumptions not specified here.

FIGURE 2 PRIMARY ENERGY USAGE: NOMINAL CASE



NOTE: This figure is representative only of the model output and should not be regarded as an official projection of SRI or any of SRI's clients since they may be sensitive to input assumptions not specified here.

FIGURE 3 POWDER RIVER COAL USAGE: NOMINAL CASE

coal become competitive and assume significant shares of the market. Thus, beyond the year 2000 these newer sources tend to determine energy prices.

In Figure 3, the usage of coal in the Powder River Basin is shown in terms of the synthetic fuels plants and mine-mouth power plants that directly use coal and also of the transportation modes that move coal for use in other regions. (The total quantity of coal shown here for the Powder River Basin includes most, but not all of, the coal classified in Figure 2 as low sulfur, Western coal.) Figure 3 clearly shows that under the input assumptions of the nominal case, gasification of Powder River coal is insignificant until beyond the year 2000.

The data shown in these three figures are a small sample of the output from the model. In addition, prices and quantities at other major locations throughout the United States and prices and quantities of distributed products including synthetic fuels, electricity, and refined products were computed.

The prices and quantities shown in Figures 1 through 3 are based on only a nominal set from among the many sets of input information used in the Gulf study. Several sets of input information were used to determine the sensitivity of the projections to changes in input information. For example, the effects of possible changes in the prices of imported crude oil, the costs of new technology, the growth in demand, and the potential reserves of domestic oil and gas were determined. Some of the projections were highly sensitive and some were highly insensitive to changes in input information. Thus, the projections in these figures should not be used by others for decision-making purposes without an understanding of the effects of the input information.

II FEATURES

We have emphasized that energy models must be tailored to specific decision problems. Features required in a model for one problem may not be required in the next problem, or the next problem may require additional features. On the other hand, considerable overlap often occurs between features required for one energy decision problem and those required in the next. With this in mind, we will describe some of the energy model features that are important in strategic, energy decision problems such as the Gulf synthetic fuels problem.

Complexity

In most cases, a decision problem concerning a new energy conversion technology, such as coal gasification, is very difficult or impossible to isolate from the energy system within which it must operate. Often, the economics of end use, transportation, and resource production will play a major role in determining what resources are produced, how they are transported, and how they are used. The complexity of the modeling problem is illustrated by Figure 4. This shows the various steps in the U.S. energy system – beginning with primary resources in the ground and their conversion into useful energy (heat in the living room or steam from a boiler).

Within the U.S. energy system, thousands of different paths lead from availability of primary resources to satisfaction of end-use demands. The path in Figure 4 begins with low sulfur coal that is mined underground, transported by slurry pipeline, converted into a gas, and used in a combined-cycle power plant to generate electricity that is distributed to residential consumers for use in a resistance-heating device to produce space heat in the living room. For the SRI-Gulf study, the model had to incorporate all the possible paths represented in this figure.

Logistics

The cost of moving energy from one location to another can be a crucial factor in the overall economics of using primary resources to satisfy end uses. For example, the cost of transporting coal by train from Western mines to Eastern markets is such that the price of coal in the East can be three times the price of coal in the West. Whereas, if this coal is converted to a liquid fuel, the transportation costs over the same distance are relatively small. Thus, in problems where transportation costs are important, the model must be geographically segmented to allow for regional price differences.

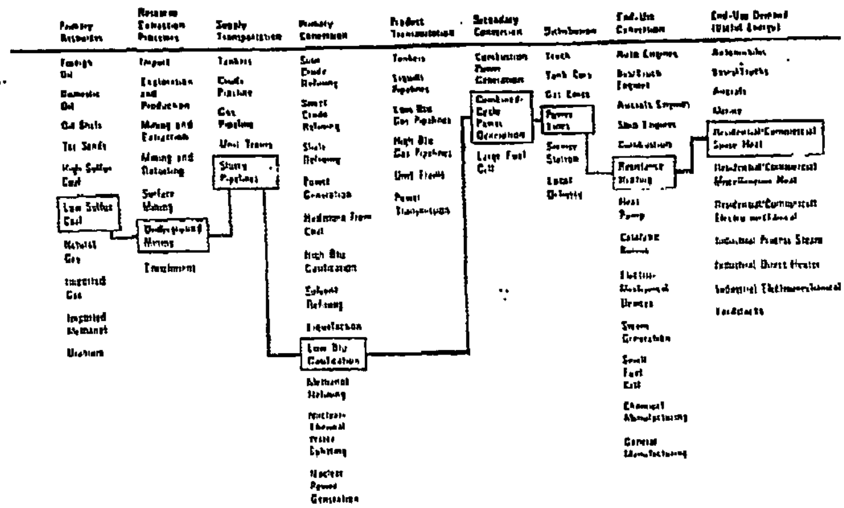


FIGURE 4 COMPLEXITY OF THE U.S. ENERGY SYSTEM

Figure 5, a map of the United States, shows the eight demand regions and the numerous coal, crude oil, natural gas, and shale resource basins used in the Gulf study.

Dynamics

Most corporate investment decisions and public policy decisions have implications over long periods of time. A model that characterizes the energy system only at specific points in time cannot reflect important changes in technology and demand nor the effect of depletion of the resource base. Also, the capacities of the energy system in any time period are highly dependent on previous investment; and current investment decisions depend on projections of future prices. Finally, in the short-term, secondary markets for scarce commodities such as pressure vessels, surface mining equipment, drilling rigs and human and institutional behavioral characteristics limit rapid change and have long-term consequences. All of these dynamic effects are incorporated in the general methodology and the existing SRI-Gulf model.

Basic Economics

Given that the supply and demand of a resource both vary with price, what is the price that will

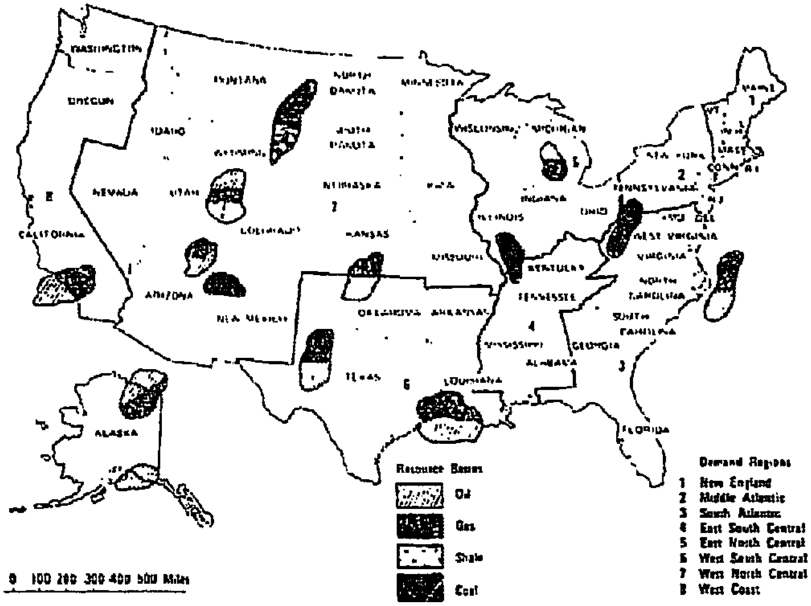


FIGURE 5 U.S. ENERGY MODEL RESOURCE BASINS AND DEMAND REGIONS

balance demand with supply? Every basic economics text discusses the solution for the case of a single resource, illustrated in Figure 6, but real situations typically entail multiple competing resources and dynamic effects. Because of the resulting complexity, many approaches to energy modeling avoid explicit balancing of supply and demand at a market clearing price. In this methodology, a computer model is used to combine curves such as those in Figure 6 with a network representation of the U.S. energy system and realistic models of the elements of the energy system such as transportation links and conversion industries. This gives the advantages of both the basic economic approach and the detail required for realism.

For example, the existing model uses supply curves to describe the total quantity of a primary resource that could be produced in a resource region at various prices. These curves are developed by holding costs and technology fixed and using available data and the judgment of exploration and production specialists to estimate the quantity of a resource that could ultimately be recovered at various price levels. Then the model is used to compute the cumulative production, plus required reserves of a resource to a given year in a specific location. This quantity is then used to find the price on the supply curve that would be required for additional production in that location and year. Finally, these prices are adjusted for the effects of inflation, technological change, short-run dynamic effects, and economic rent (the difference between the price of a resource and its cost). The result is a realistic, dynamic description of resource supply that is consistent with basic economics.

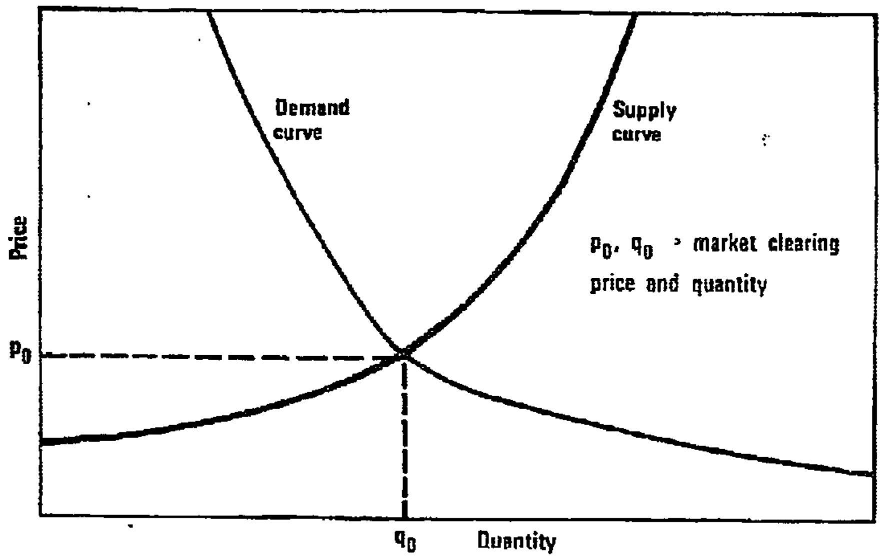


FIGURE 6 FUNDAMENTAL ECONOMICS OF SUPPLY AND DEMAND

Meaningful Data

A crucial aspect of any model is that the inputs be meaningful to those who must provide and review them. Some approaches to modeling use regression analysis on large amounts of historical data to determine the parameters of the equations that make up the model. Other approaches use abstract inputs such as cross-elasticity coefficients and input-output coefficients, or arbitrary constraints on growth rates and resource availability. The problem with such input is that the data are often unintelligible to specialists who have the knowledge to judge its accuracy. However, a model that decomposes an energy system into its basic elements — such as production, transportation conversion, and end-use technologies and behavorial considerations — facilitates description of each of these elements in the most meaningful way. For example, the SRI-Gulf model uses capital cost, operating cost, and thermal efficiency data obtained from industry specialists to describe conversion and transportation industries. Structuring model input into numerous specialized data areas enables experts with in-depth, specialized knowledge to contribute data without having to understand all of the details of the model. Furthermore, this form of data can be communicated easily to anyone who wants to understand the model.

Specific Features

Some of the specific features in the existing SRI-Gulf model are described below.

Economic Rent -- Owners of energy resources will not sell their resources at cost plus return on investment if they believe that they can obtain a higher price. Thus, the price of a resource is determined not only by the cost of producing it, but also by competitive fuel prices and the scarcity of the resource. Economic rent, the increment above marginal cost that must be paid to a resource owner to induce him to sell, is large when the price of a resource is rising rapidly as a result of rapid depletion. This phenomena of economic rent is fundamental to energy pricing and incorporates lease bonus payments and windfall profits.

End-Use Demand Elasticity -- In response to higher prices of a fuel, users may reduce consumption by turning down the thermostat, using less steam, or driving less. Alternatively, they may substitute a less expensive fuel. In modeling end-use demand, it is important to distinguish between the effects of true reduction in the consumption of usable energy and the substitution of other fuels. The existing model emphasizes the substitution effect because the Gulf synthetic fuels decisions were somewhat sensitive to it. The existing model excludes usable energy elasticity because sensitivity analysis showed that the decisions were relatively insensitive to the price elasticity of usable energy over the range of prices encountered. Nevertheless, detailed price elasticities for usable energy demand can be incorporated within the existing model for analysis of problems sensitive to usable energy elasticity.

Financing, Accounting, and Taxes -- Significant differences in financing practice, accounting conventions, and taxation exist among the various sectors of the energy market. For instance, the financing of regulated public utility investments differs significantly from that of oil company investments. Also, accounting and tax conventions differ from project to project. The model explicitly accounts for these differences.

Market Share -- Under perfect competition, the allocation of demand among alternative sources is trivial -- the demand is always allocated to the lowest priced source. In the real market, however, behavorial considerations and market imperfections such as consumer fuel preferences, discriminating pricing, and variations in costs all come into play. The model describes such phenomena by using empirically developed market share curves to relate market shares to prices.

Initial Energy Balance -- The current U.S. energy balance is a starting point for the evolution of the energy system over time. The current allocation of demand among existing sources must be included as input to the model so that the dynamic effects incorporated in the model are provided the proper initial conditions.

Secondary Industries – In times of rapid expansion of capacity, growth is often discouraged by high prices of equipment and manpower used to construct new plants. Thus, the model includes approximate submodels of secondary industries producing such critical items as drilling rigs and surface mining equipment. These submodels compute the prices of secondary items for a given demand pattern. When a higher price is required for a secondary item the result is higher capital costs for those plants requiring the items.

Behavioral Lag – Most organizations and individuals respond slowly to changing economic conditions. Instead, we often wait to see proven success before we change our ways. In addition, lags are caused by the time required to plan and construct new facilities. The net effect is that economic actions respond in part to past prices as well as to current ones. Clearly, uncertainty and risk aversion contribute to this effect. Because of the importance of this effect, empirically determined lag parameters are used in the model.

Technological Change – Learning effects are important in determining the prices of future energy products. Over time, technological improvements lower the capital cost of existing processes (expressed in constant dollars). In addition, entirely new technologies such as fusion or coal liquefaction become commercially available and must be included. Technological change is incorporated in the model by using simple learning curves and nominal dates for commercial availability.

The features described in the above paragraphs illustrate the realism that can be built into models constructed by using this methodology. Because so many aspects of an energy system can be integrated in an energy model using this methodology a major by-product of a model is the understanding developed concerning how these aspects relate to each other and to energy decisions.

III COMPUTATION

The application of the basic economic concept of balancing supply and demand to an imperfect market system that contains essentially thousands of supply and demand curves is an important consideration. The equilibrium mechanism of the market supplies a clue on how to apply this concept. If the market price is too low, demand exceeds supply and the price will rise to the point where supply and demand balance. Conversely, if the market price is too high, supply exceeds demand and thus the price will fall. The network price iteration algorithm that provides the foundation for the SRI methodology takes advantage of this basic market mechanism.

The Energy Network

To illustrate, we will use the partial network shown in Figure 7. The resource supply curves are at the bottom; the usable energy demand curves are at the top. In between these curves is the network describing the entire energy system. The SRI-Gulf model has about 2,400 materials, processes, and transportation links. A *material* is a primary resource, product, or usable form of energy at a specific location. A *process* represents a sector of the energy industry such as coal mining or gasification at a specific location or a class of consumers using a particular energy-consuming device. A *transportation link* represents the economics of moving a material from one location to another.

To get a sense of the many paths in the network, consider first the path where coal is mined, converted into synthetic (high Btu) gas, piped to a demand center in a demand region, distributed to industrial users, and consumed as boiler fuel to produce steam. The same end-use market could be supplied by coal transported by unit train, distributed to the same industrial users, and used in a boiler to produce steam. These two paths can be traced in Figure 7. In the SRI-Gulf model, there are fourteen end uses (such as industrial steam) in each of eight demand regions and thirty primary resource supplies (such as coal) in the various resource basins illustrated in Figure 5. The alternative technologies in the model include all important types of electric power generation (producing base, intermediate, and peak load power), sweet and sour crude oil refining, shale oil refining, high- and low-Btu coal gasification, coal liquefaction, solvent refining of coal, methanol from coal, and hydrogen production from coal and nuclear fuel.

Network Price Iteration Algorithm

The network price iteration algorithm operates in much the same way that the U.S. energy system operates to determine the prices that result in a balance between supply and demand. To illustrate, we begin at the bottom of Figure 7 and roughly estimate the quantity produced over time of each of the primary resources and products throughout the network.* On the basis of these estimates of primary resource production, the resource supply curve and other dynamic information are used to compute tentative prices of primary resources in each time period.†

We then move up the network along all paths simultaneously, and compute tentative prices of the products. These product prices are computed by using models that account for the capital and operating costs of each of the conversion processes, transportation links, distribution links, and end-use conversion processes that describe the energy network. Where two or more sources of a material compete, we use appropriate rules for determining the price of the material, given the prices from the sources. When we reach the top of the network, we have computed tentative prices of usable energy for each end-use sector in each demand region over time.

At the top of the network, we begin a downward pass. We apply the prices of usable energy to the usable energy demand curves to determine the quantity of energy needed for each end use in each time period. As we work down the network, we allocate the required quantity of materials to competing sources based on the tentative prices computed on the upward pass. In addition, the required quantities are increased to account for the thermal losses in energy conversion and transportation. When we reach the bottom of the network, we have a new estimate of the required quantity in each time period for each of the primary resources. We then repeat the iterative process: the new estimates of production lead to new prices that are passed up the network and result in new demands that are passed down the network. This iterative process is continued until it converges; that is until no significant change in prices and quantities occur on two successive iterations.

This network pricing algorithm is summarized in Figure 8. In practice, additional techniques are incorporated in the algorithm to guarantee convergence and to account for the behavioral and other features of the methodology mentioned earlier.

It is important to recognize that the dynamic aspects of this approach are not equivalent to using a static model in each of the time periods. Rather, the prices and quantities in each period are determined

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*In the current SRI-Gulf model, the time horizon is the year 2025. The 52 years from 1973 to 2025 are broken into 17 time periods. These time periods are of unequal duration to allow more detail in the years that are important for the decision problem.

†The price of a primary resource also depends on economic rent and the price of secondary materials such as drilling rigs and surface mining equipment.

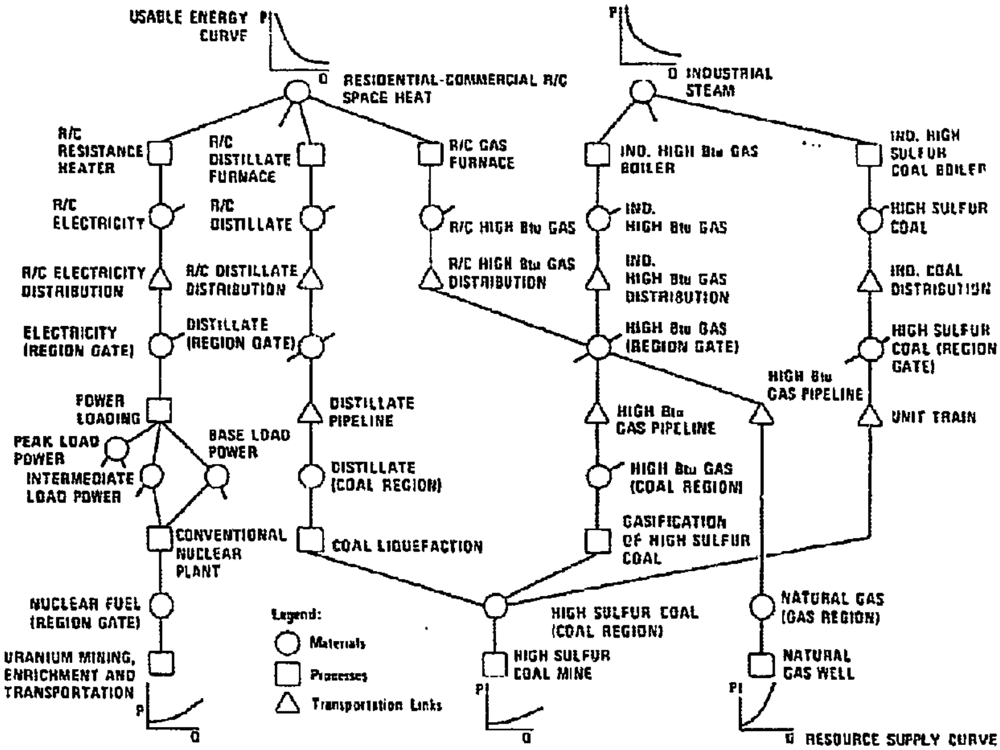


FIGURE 7 ELEMENTS OF THE ENERGY NETWORK

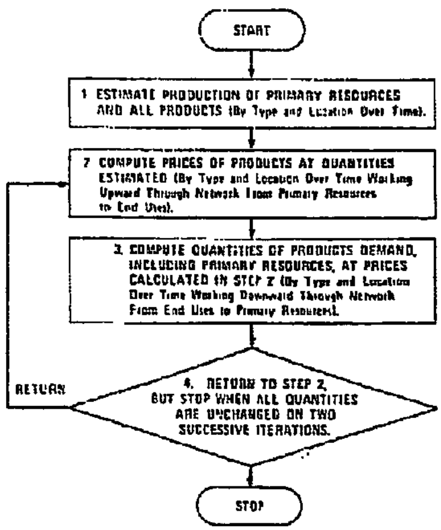


FIGURE 8 NETWORK PRICE ITERATION ALGORITHM

by dynamic relationships that interrelate both past and future prices and quantities. Current prices depend on future prices because the price of a product required to justify a new plant to produce that product is affected by projections of future prices. Also, current capacity decisions depend on previous prices and decisions because of resource depletion, existing capacity, and behavioral lag.

Another important computational consideration is that models produced by this methodology are nonlinear and usually unconstrained. Linear programming is not used as a computational tool. The mathematics of this methodology reduce to the iterative solution of a system of nonlinear equations that are the economic, technical, and behavioral relationships that describe an energy system. The solution of these equations is the set of prices and quantities that form the output of the model. Arbitrary constraints on the availability of scarce resources such as limitations on plant capacity, primary resources, and surface mining equipment are not needed in the model as they are in some other approaches. In this methodology, we explicitly model the higher costs of such resources as they are depleted (resource supply curves) or when there is a temporary shortage (secondary industries model). In the case of natural gas regulation, however, constraints on the price of gas as determined by regulatory policy are included; and the secondary reactions of the market, such as supply-demand imbalance, are explicitly represented.

Driving Forces of the Model

At this point, the question of "what drives the model" often arises. Paradoxically, supply and demand curves are the key inputs required to forecast supply, demand, and prices. The important difference between the input data and the output forecasts is that the inputs are price-quantity curves while the outputs are market clearing (equilibrium) quantities and prices. To illustrate, in the textbook case of Figure 6, the supply and demand curves are inputs while the market clearing price and quantity, p_0 and q_0 are outputs. Many conventional approaches to energy forecasting attempt to directly predict market clearing prices and quantities over time whereas in this approach prices and quantities are calculated on the basis of more fundamental inputs such as supply and demand curves and the economics of conversion, transportation, and distribution. Thus, the model does not eliminate the need for expert judgment. Rather, it changes the task from directly predicting future prices and quantities to modeling relationships between prices and quantities.

IV APPLICATIONS

No single energy model can address the critical issues of every energy problem. However, by building models that are fundamental, comprehensive, and decision focused and by measuring sensitivities to various inputs and assumptions, we can improve our understanding of what is important. In this way, information gathering, analysis, and management attention can contribute to improving the quality of decisions.

Corporate Applications

The existing SRI-Gulf model and the discussion of the Gulf synthetic fuels problem serve as an example of what can be accomplished by using the methodology described here. For many corporate applications entailing U.S. energy markets, the model can be used with relatively minor modifications to improve the detail and information in areas to which the decision is sensitive. For some classes of decision problems, the model could be used as a general planning and forecasting tool, but care would have to be exercised in the interpretation of the model output. For problems having an international or specific regional scope, detail can be enhanced or reduced as needed. For example, a world energy model presumably would use less detail in the U.S. markets, but could use essentially the same computer programs.

Government Applications

The need for modeling in government energy decision making is at least as great as that in business decision making. Two main differences are evident between public and private sector decisions. First, the government makes decisions regarding taxes, price controls, import restrictions, leasing policy, environmental controls, R&D expenditures, and other instruments of public policy. The purpose of these policy decisions is to achieve a more socially desirable functioning of the nation's energy markets. Ordinarily, however, it is extremely difficult to predict what effects these decisions will have on private sector behavior. Often secondary reactions of producers and consumers dilute the intended effects of decisions. In some cases, the decisions may actually be counterproductive. For example, a decision to increase taxes so as to reduce consumption of one form of energy may have little effect or may lead to adverse environmental and economic effects through substitution of other fuels.

The second characteristic that distinguishes government decisions from private sector decisions is the great complexity of social preference questions encountered in creating public policy. In addition to being concerned about energy prices and quantities, government policy makers must try to balance outcomes related to environmental pollution, employment, safety, balance of payments, dependence on foreign supply, industry profits, taxes, and government expenditures. Calculating these outcomes is a difficult, but feasible task. Once the basic prices and quantities of energy products are established, value judgments can be used to evaluate tradeoffs among the social and environmental outcomes. These judgments form the basis for overall measures of social benefit and cost. These measures can then be used for evaluating alternatives just as profit was used as an overall measure in the Gulf study.

Techniques for analyzing the social preference aspects of public policy decisions have been evolving rapidly in the past few years. SRI has developed and applied such techniques in project work for various agencies of the U.S. Federal Government and for foreign governments. These social preference techniques, together with this methodology for constructing energy models that account for secondary reactions of producers and consumers, provide a comprehensive, logical approach to the analysis of national energy policy decisions.

Other Applications

The methodology itself has broad potential application beyond energy problems. It is useful in constructing models of complex markets characterized by interproduct competition and regional differences arising from product transportation costs. In essence, it allows the construction of practical, realistic models in areas where simple economic models have been attempted, but have fallen short of predicting market behavior. Such problem areas include food, land use, raw materials, international trade and finance, and monetary-fiscal policy. As our society becomes more interdependent and capital-intensive, we can expect to see the development of increasingly more comprehensive and realistic models.

Appendix C

REGULATION OF NATURAL GAS

APPENDIX C

Regulation of Natural Gas

Introduction

The SRI Energy Model inter-relates the various decisions made in the energy market in order to project a consistent set of energy prices and quantities. In its normal mode of operation, the model assumes no price or quantity regulation of any kind. It assumes that market and behavioral forces are generated by the interaction of a large number of decision makers, none of which can dominate the market through his individual actions. This assumption is probably descriptive of the interactions among energy producers and consumers, but clearly cannot handle questions of government regulation, where the government can change the operation of the market through unilateral action.

In order to understand price regulation of natural gas, we must model the environment in which individual decisions will be made under the price regulation. That is, we must understand how individual decision makers, acting in their own interest, will tend to act under regulation. To illustrate, gas price regulation will dry up gas supplies if the producer is not allowed to sell each increment of gas for at least its incremental lifting cost. On the other hand, gas price regulation will not dry up gas supplies if the producer is allowed incremental lifting cost for each increment.

In this section, a methodology will be developed for modeling how gas producers' decisions will be affected by natural gas price regulation. These models then can be incorporated into a comprehensive energy model such as the SRI Energy Model to test the effect of gas price regulation on the entire energy system. We will give special attention to changes in producers' and consumers' surplus under price regulation.

Analysis of Regulated Markets

The starting point of the analysis is consideration of the supply and demand curves that exist in the market before price regulation. Figure C-1 shows these well known curves. The non-regulated equilibrium is price p_e and quantity q_e.

Consider the supply curve shown in Figue C-2. It shows that more gas will be offered for sale as the price in the market gets higher. The cause of this is the fact that there are many sources of gas, and they differ in cost of production. The figure constructs a hypothetical supply curve by ranking the sources by increasing cost. If the price is above p_2, it is economical to produce all on-shore gas at depths up to 15,000 feet, and all off-shore gas in water less than 800 feet deep. However, the price must be raised to p_3 before all the possible sources of synthetic gas would be offered for sale in the marketplace.

A similar exercise is performed for the demand curve in Figure C-3. As the market price drops, more gas is demanded. The hypothetical demand curve orders the uses of natural gas by how much a user is willing to pay

FIGURE C-1: SUPPLY/DEMAND BALANCE

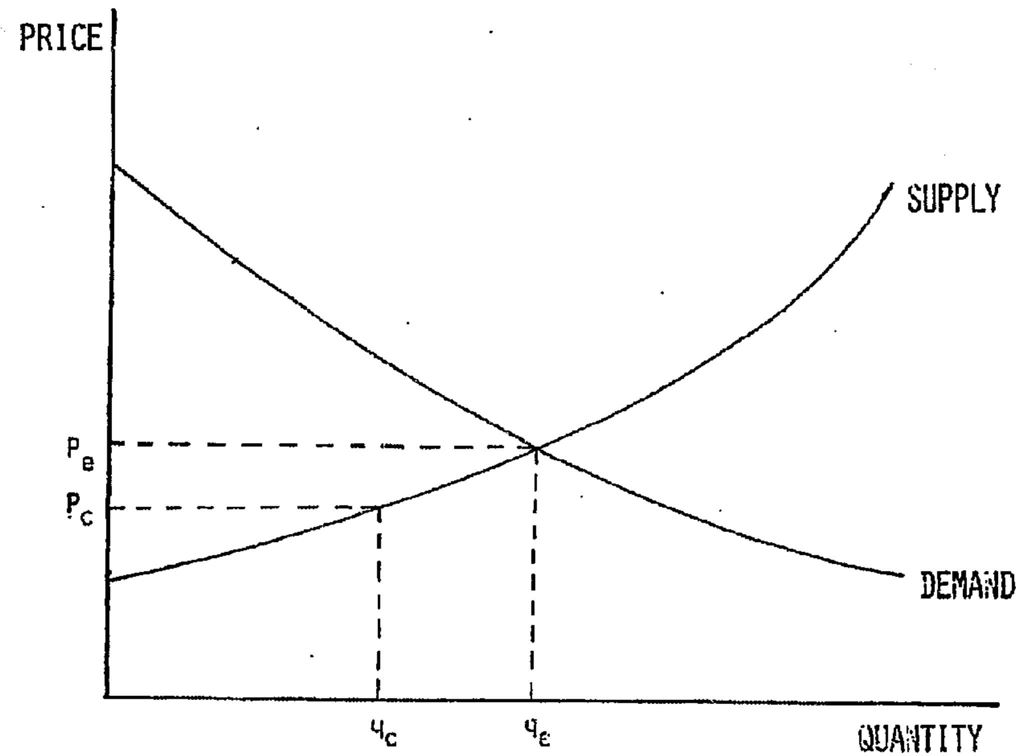


Figure C-2

THE SUPPLY CURVE

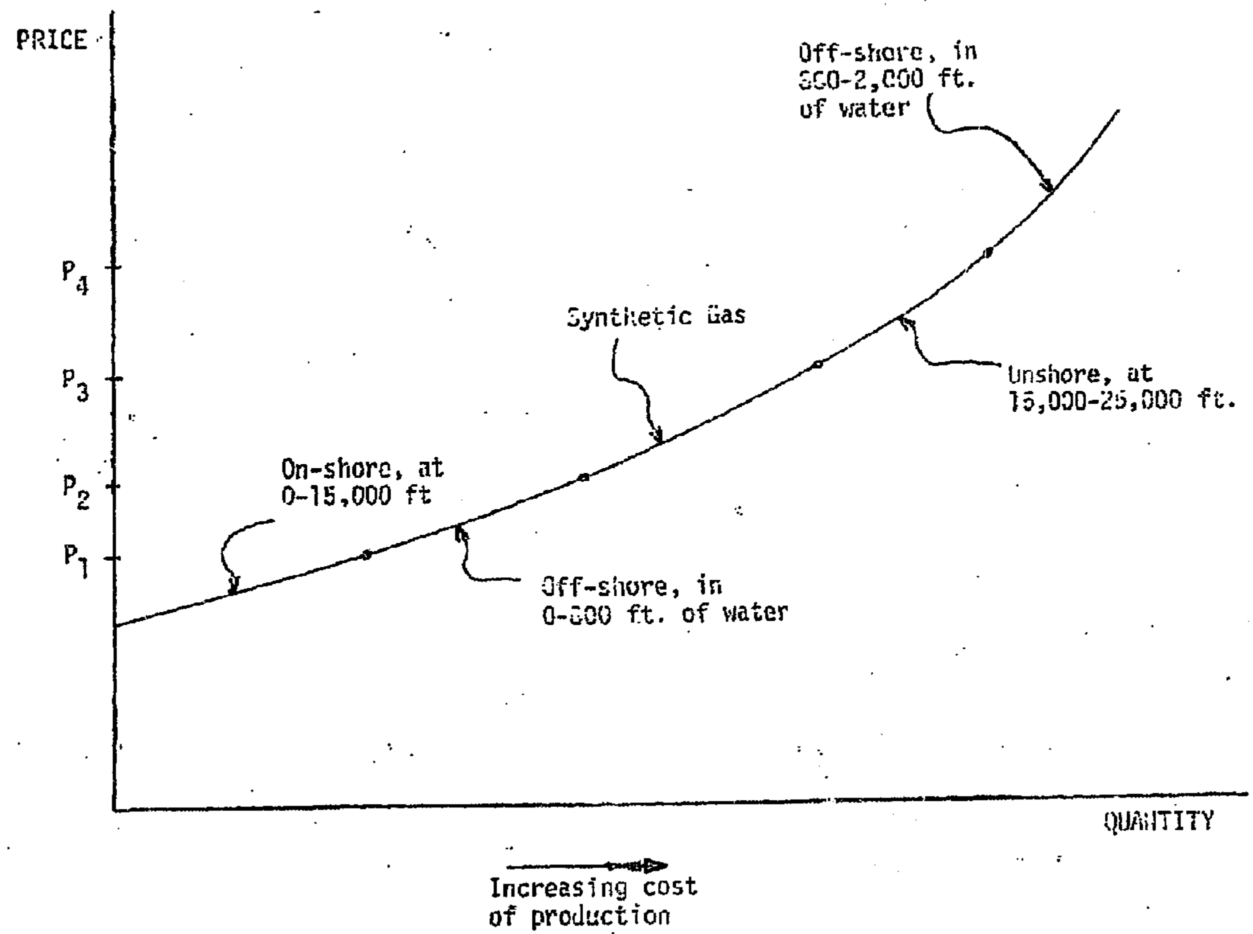
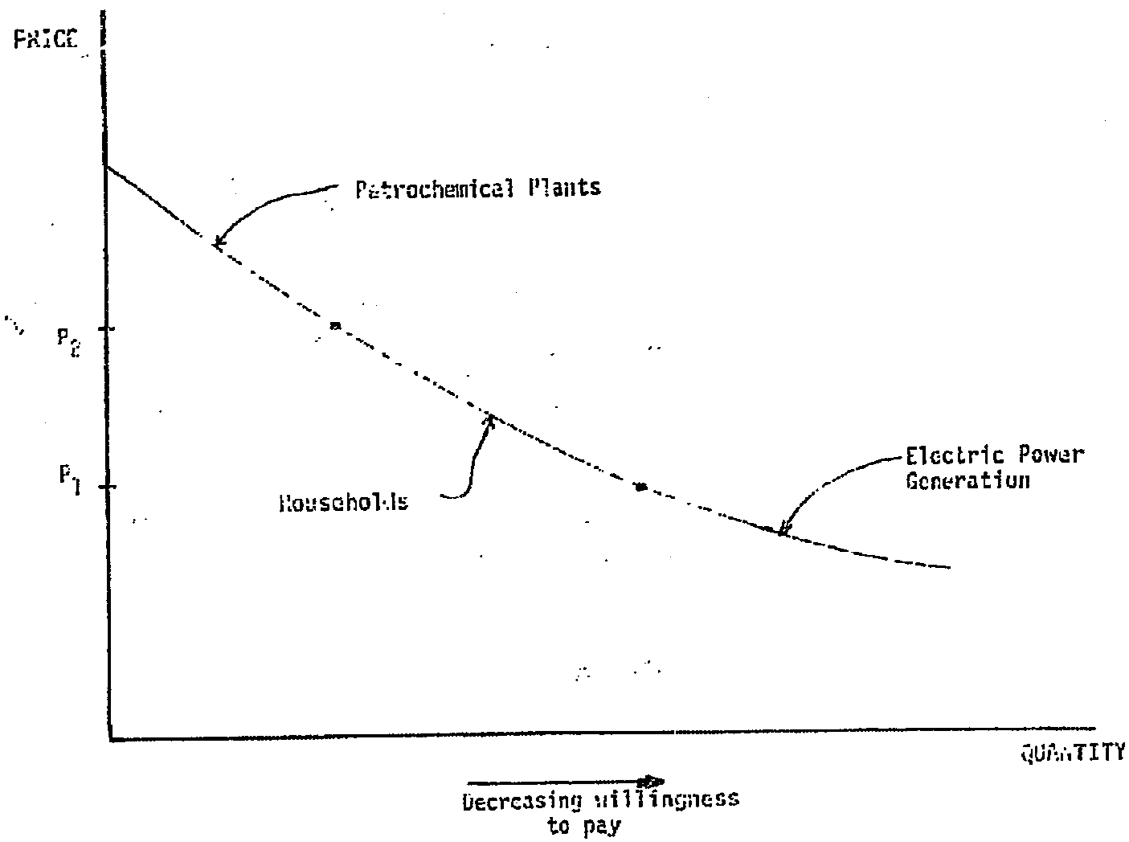


Figure C-3

THE DEMAND CURVE



for the product. If the price is p_2, only petrochemical plants will purchase gas. The price must fall below p_1 before gas would be used for electric power generation.

Price control is implemented by introducing a price ceiling, p_c in Figure C-1. No supplier (producer) of natural gas is allowed to sell gas at a price that exceeds p_c. If p_c is less than p_e, there will be a shortage of natural gas, because suppliers will only offer q_c for sale. (If p_c is greater than p_e, the price ceiling will not affect the market price and quantity.)

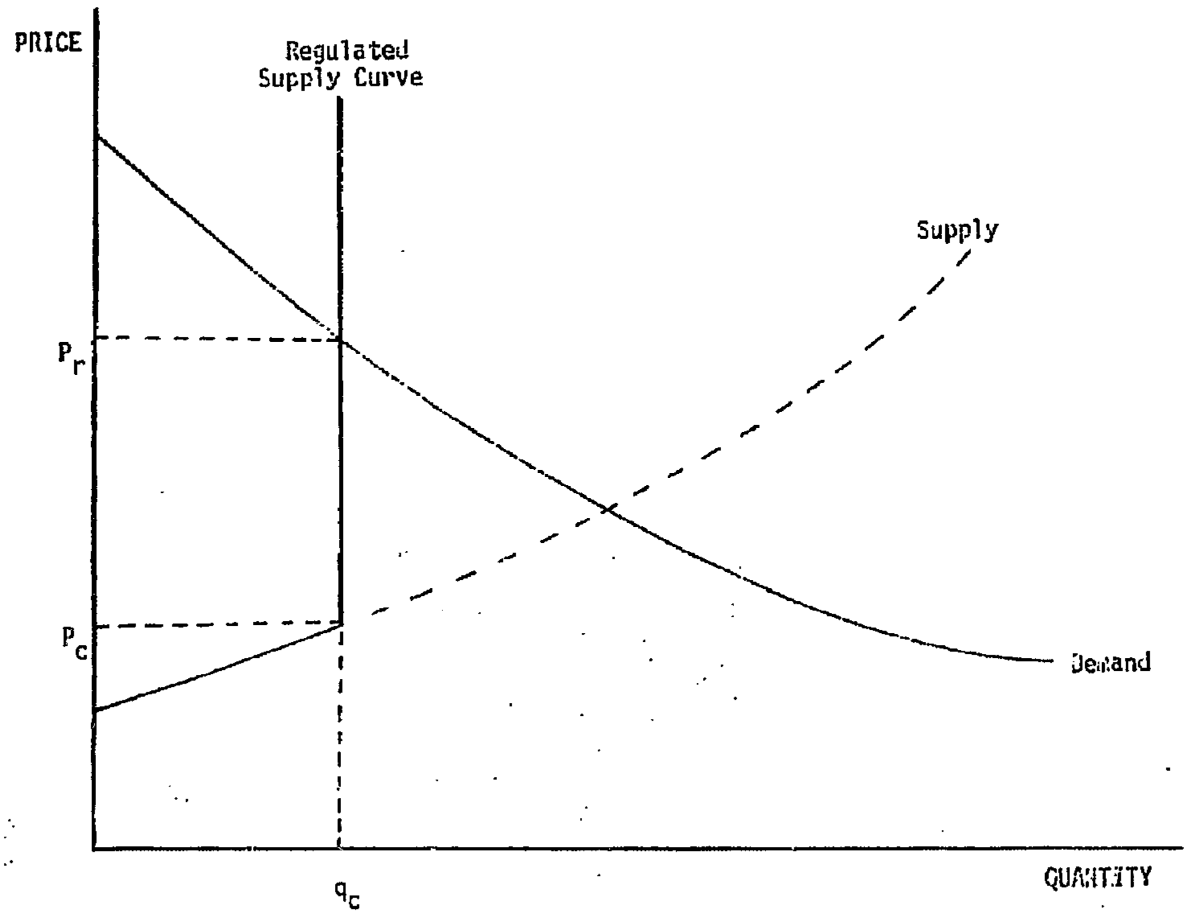
It is convenient to think of price regulation as changing the supply curve as shown in Figure C-4. The original supply curve is followed until p_c is reached. Then the supply curve goes infinite, indicating that there exists no price that will elicit a larger quantity into the market. The quantity demanded is q_c. The supply curve intersects the demand curve at p_r. If there is no misallocation of gas, the marginal value would be p_r. That is, if the gas is allocated according to who would pay the most for it, the last agent allocated gas, and the next person to receive gas if there was one more small increment of it, value the gas at p_r. P_r is what economists call a shadow price. However, they would only pay p_c due to the regulated price ceiling imposed upon the market.

Figure C-5 looks at producers' and consumers' surpluses in the regulated market. The producers' surplus is the difference between what the product sells for, p_c, and what it costs them to make it, represented by the point on the supply curve. The producers' surplus for quantity q_c is the cross-hatched area between p_c and the supply curve. The consumers' surplus is the difference between the consumers' valuation of the gas, represented by the demand curve, and the price paid for the gas, p_c. The total consumers' surplus at quantity q_c is the cross-hatched area between the demand curve and p_c. The regulation of price causes a loss of total surplus, the solid area. There are agents on the demand side of the market that are willing to pay more for the gas than it costs producers to produce it, and the quantity between q_c and q_e represents the lost consumers' plus producers' surplus opportunity.

The preceding situation does not represent the total effect of regulation that exists in the natural gas marketplace; the Federal Power System uses an allocation system to allocate the existing quantity of gas. Since this scheme is not based upon the economic reasoning above, so that p_r is the marginal valuation of gas, it is necessary to do more detailed modeling. The allocation system breaks gas users into priority classes, and allocates the gas to the higher priority classes, Priority Classes I and II, first. Remaining quantities of gas are then given to the other priority classes if available.

Figure C-6 represents the markets under the allocation scheme. The total market is segmented into Priority I and II users, and all other priority classes. The regulation agency has divided the available gas supply, q_c, between the two segments, giving q_1 to Priority I and II users, and q_2 to the other priority classes. This allocation scheme determines the value of an incremental gas quantity in both markets. These are represented by V_1 and V_2 for the Priority I and II and other markets respectively. As drawn, Figure C-6 shows an inefficient allocation. Since the value in the

FIGURE C-4: PRICE CEILING



PRODUCERS' AND CONSUMERS' SURPLUS IN REGULATED MARKETS

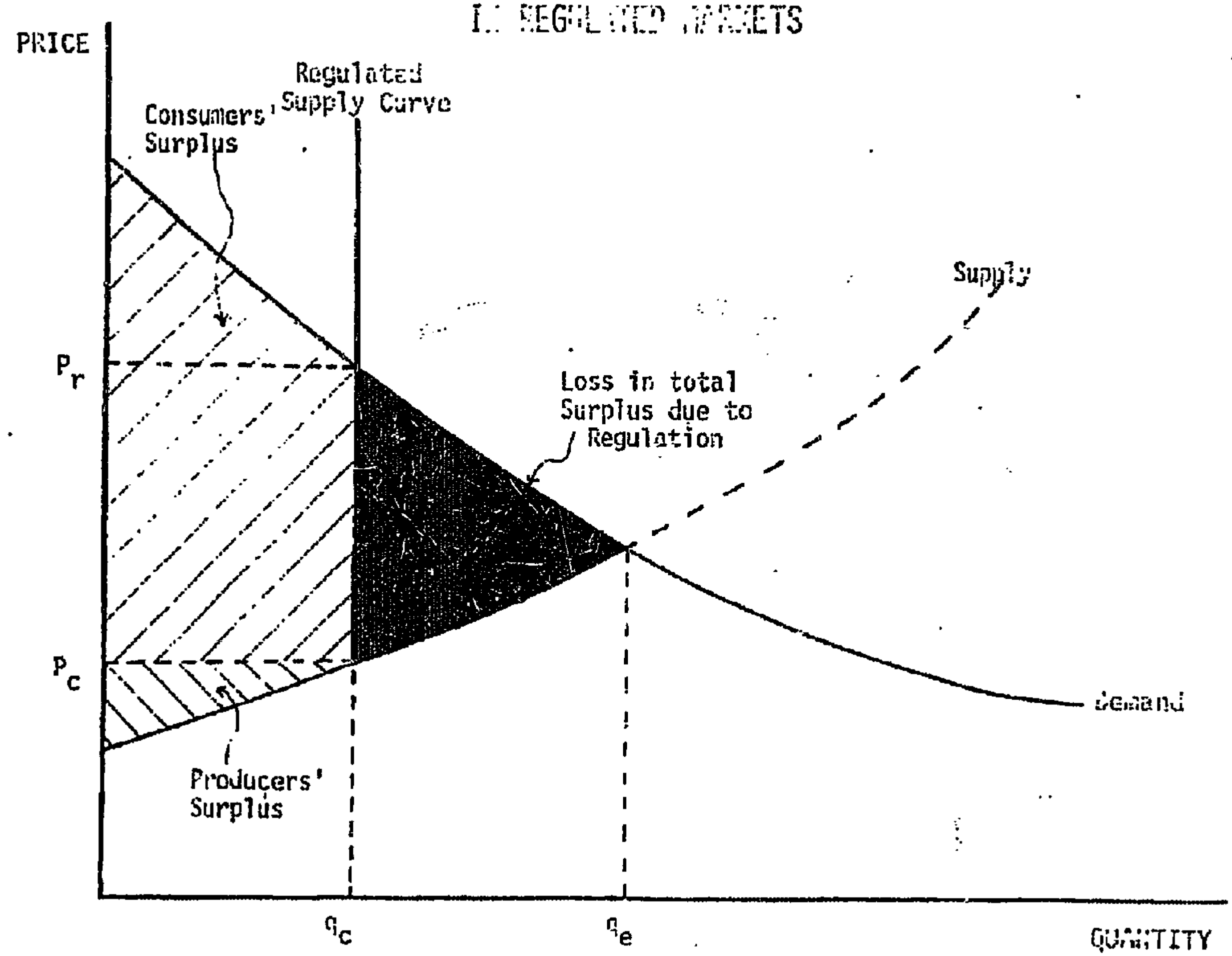
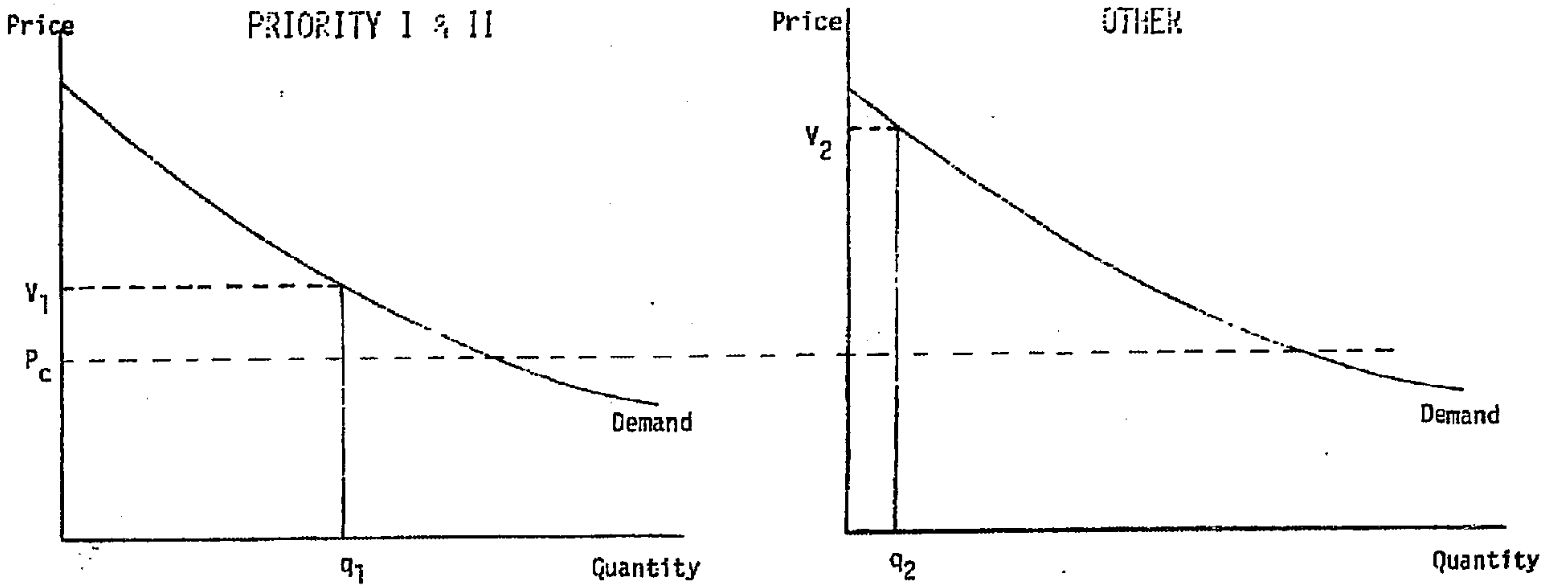


Figure C-6

THE GAS MARKET SEGMENTED
BY PRIORITY CLASS



$q_1 + q_2 = q_c$

other market, V_2, is greater than the value in the PI and II market, V_1, consumer surplus could be increased by transferring gas to the other market until the marginal values of incremental gas were equal. In this case the two market segment values would equal the total market value (shadow price) p_r which would exist if the quantity of gas q_c was allocated by user value. (This allocation of q_c would not recoup the lost total surplus from Figure C-5.)

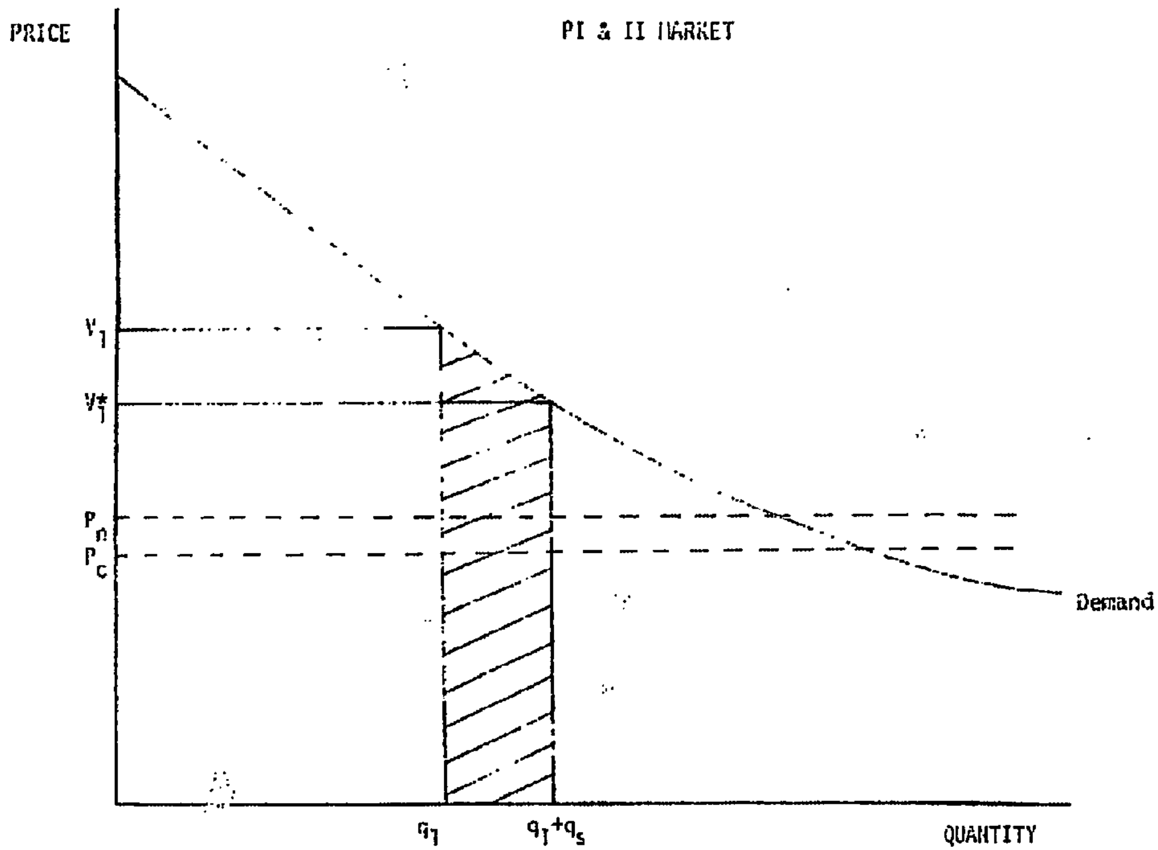
The above discussion structures the natural gas market under price regulation and allocation. To understand consumers' and producers' surplus in such a market, consider the following example. Assume that the government causes a coal gasification plant to be built. The gas produced is all allocated to the PI and II market. A new market price is calculated by "rolling-in" the coal gas. That is, the total amount paid before government action is added to the cost of synthetic gas cost, and this figure is divided by the sum of the original quantity plus the quantity of coal gas. If the quantity of synthetic gas is q_s, and its cost is c_s, then the new price reflecting the roll-in is

$$p_n = \frac{p_c \times q_c + c_s}{q_c + q_s}, \text{ and}$$

the new quantity is $q_c + q_s$. The PI and II market has a new quantity of $q_1 + q_s$, while the other market quantity remains q_2. This is shown graphically in Figure C-7. (It is assumed that p_n is low enough so that quantity $q_1 + q_s$ would still be purchased.) The value of the gas is the cross-hatched area in the figure. The demand curve represents the willingness of the gas consumer to pay, so that the area between the demand curve and the axis, and the q_1 and $q_1 + q_s$ lines represents the value of the incremental gas. (A cost benefit analysis would compare this value with the costs of producing q_s.)

It would be valuable to know the marginal values before and after the introduction of synthetic gas, V_1 and V_1^*. However, since the markets do not clear, these quantities cannot be observed. If the demand curve for the PI and II market is known, then the values can be solved for. If the demand curves are not known, V_1 and V_1^* can be bounded. If $q_1 + q_2$ is purchased in the PI and II markets, then V_1^* is greater than p_n. This is seen by looking at Figure C-7. Also, p_r is greater than V_1. Previous discussion demonstrated that p_r is the value (shadow price) of the gas if it is optimally allocated. Thus, p_r has to be at least as larger as V_1. If the allocation system assigns any gas non-optimally by assigning more gas to the PI and II market, then the value of the marginal increment of gas drops. Thus,

$$p_r \geq V_1 \geq V_1^* \geq p_n.$$



ADDITION OF SYNTHETIC GAS
Figure C-7