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AN EVALUATION OF ALTERNATIVE STRATEGIES FOR SITING COAL GASIFICATION FACILITIES IN THE UNITED STATES

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AN EVALUATION OF ALTERNATIVE STRATEGIES FOR SITING COAL GASIFICATION FACILITIES IN THE UNITED STATES

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CHAPTER I

INTRODUCTION

This study investigates and compares the policy implications of various coal gasification siting strategies in the United States. A general spatial allocation model(e.g., Scott, 1971) of the synthetic, imported, Alaskan, and natural gas supply system is constructed and manipulated to identify the consequences of a number of possible policies and events that can affect fuel supply. The intent is to predict the locational and policy consequences of alternative courses of action for developing a coal gasification capability in the United States, so that policymakers can determine siting strategies cognizant of their costs, impacts, and other implications. Different gaseous fuel demand estimates are employed so that the results will be instructive for a wide range of future conditions.

The results of the analysis are normative in that they identify the optimum way in which particular synthetic gas supply systems can be constructed given a number of simplifying assumptions. Although the eventual form of the synthetic gas supply system in the United States may not actually resemble any of the forms described here, a comparison of the "ideal" to the "real" can provide insights about the economic tradeoffs and future development options of a real system. As noted by Chisholm(1971:130), "...where the real world diverges from the normative prescription a case can be made for the use of legislation or other devises to bring reality into line with the prescription." The normative models presented here can be effectively used as guides to better gasification siting strategies and flows of coal and gas.

Perhaps more realistically, the modelling approach can be used as a devise for comparing the spatial implications of different norms, expressed as different constraints on a spatial allocation optimum. Optimally is a subjective term, although it is most often equated with economic efficiency. Conflicting interest groups; a changing legal and institutional framework; and insufficient, unreliable, and biased information limit the value of the economically "efficient" solution as a viable planning goal. For example, in a participatory democracy, the Pareto "optimum" may be more realistic than the "optimum" derived from most location-allocation models. Such an optimum is one in which no further re-allocation of resources can be made to help some individuals without simultaneously hurting others.[1] Other aspects of the supply system may be more im-

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[1]"As Pareto expressed it, when the community can adopt a

portant to policymakers than its economical efficiency. Morrill and Symons(1977:224), for instance, speaking of the location of public facilities, attack the usefulness of classical transportation models as planning tools. "Contrary to the presumption of location theory, an efficient location pattern that maximizes system profits or minimizes system costs, including travel, may result in socially unacceptable inequality in access over space...."[1] Therefore, an attempt is made in this study to consider goals other than system efficiency.

To achieve the objectives of this study, a general method for analyzing public sector location problems is adopted(see, e.g., Hillsman, 1976). First, "ideal plans" for the siting of the facilities are found. In these cases, the ideal plans are those which minimize total costs to the system. Adjustments are made to the parameters and constraints of the model, and additional simulations are conducted, reflecting other policymaking criteria and conditions(such as environmental protection, regional fuel independence, and the provision of

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policy procuring greater benefits for all individuals, it should pursue it as long as it is advantageous to all, and 'where that is no longer possible...it is necessary, as regards to advisability of stopping there or going on, to resort to other considerations foreign to economics--to decide on grounds of ethics, social utility, or something else, which individuals it is advisable to benefit, which to sacrifice(Samuals, 1974:44).

[1]McAllister(1976:62) also recognizes the insuitability of rigid objective measures for certain types of location problems. The "concept of 'optimal' public facility location has no objective basis. Social welfare has both equity and efficiency components; both are important. Location decisions typically require that the two criteria be compromised; this necessitates a subjective judgement."

continuous service). Thus, the multiple solutions represent " a number of good plans along a frontier of possible plans" (Hillsman, 1976:145).

The presentation of multiple simulations that consider a range of possible planning goals can be of substantial value in the formulation of public policy. Leontief(1976:34), for example, strongly advocates formulating "alternative scenarios" as a basis for deriving national policy.

> ...a planning process should start out not with the formulation of what theoretical economists refer to as the general "objective function", but with the elaboration of alternative scenarios each presenting in concrete, nontechnical terms one of the several possible future states of the economy.

Accordingly, "alternative scenarios" of possible ways of providing gaseous fuel in the future are presented, and the nature and degree of the variance in the simulation results is an important part of the contribution of the analysis.

Research involving simulations of siting alternatives has the potential to provide a bridge by which geography can apply its scientific rigor and methods of analysis to contribute to meeting society's needs. Smith(1974:289), for example, says that geography is shifting away from "...the mechanistic approaches of the quantitative and model-building revolution, toward more involvement in contemporary social issues along with a renewed interest in applied geography and public policy." Thus, the contribution of this study is not a theoretical contribution to spatial allocation analysis but the application to an important contemporary problem of a tool which has already been refined and tested.

The need for employing a spatial perspective in formulating and solving policy problems has been identified by O'Loughlin (1973:36). He notes that one of the strongest contributions geographers can make to the study of public policy is through the use of spatial allocation models.

> Perhaps the greatest contribution by geographers in policy studies has concerned questions of optimal or best location.... Another advantage of this approach, once the optimal location has been identified by whatever criteria deemed appropriate, is to evaluate existing facility locations by a comparison to the optimal. Thus far, most criteria have been economic (least cost sites, etc.) but if Pareto optimality is not desired, optimal locations can be identified in those instances also.

Spatial allocation methods can aid in forecasting the the future locations of new energy supply facilities under different conditions and for different criteria of optimality. The location of these facilities will affect the distribution of impacts and benefits, the efficiency of the system, and the costs to the system as a whole. Knowing the feasibility of a site under a variety of different possible conditions can aid in site selection, construction logistics, lawmaking, and regional and national planning. A site which incurs low transport costs may have high environmental and social costs associated with its use. On the other hand, a particular law or regulation may eliminate the use of an economically advantageous location. Presenting such alternatives for concrete cases can help to inform the general public about different strategies to solve a national problem, and the important tradeoffs involved. Quantifying the differences between alternative siting strategies to achieve certain goals can illustrate the costs and benefits involved in deploying new and untested technologies. Such information may aid decision-makers in making better decisions than would otherwise be the case.

Therefore, instead of determining the optimal location of new facilities, the approach here(as in "welfare economics" (see, e.g., Mishan, 1968)) is concerned with how alternative siting strategies might affect different parties to siting decisions. More specifically, this study is a type of policy analysis which focuses upon the consequences of different siting strategies for deploying synthetic gas facilities together with policies and implementation programs that affect those strategies.[1]

Siting new energy facilities and overcoming barriers to commercialization are major roadblocks to developing coal

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[1]It may be argued that since the study focuses upon the implications of deploying a particular technology, the study is more of a technology assessment than a policy analysis. However, the aim of the study is not to assess the primary and secondary impacts of coal gasification utilization but to identify the implications of different policies of using synthetic gas and to present decisionmakers with an analysis of feasible options and their costs and benefits. A discussion of the scope and aim of policy analysis is presented by Beckman(1977). Ukeles(1977:223) defines policy analysis as the "...systematic investigation of alternative policy options and the assembly and integration of the evidence for and against each option. It involves a problem-solving approach, the collection and interpretation of information, and some attempt to predict the consequences of alternative courses of action."

gasification based supply systems. In fact, some experts maintain that finding sites for new energy facilities presents the major policy problem hindering enhanced domestic energy supply(Weinberg, 1977). For instance, the Federal Energy Administration(1975) noted that "...delays in energy facility site designation and preconstruction approvals (are) the most important problems that must be resolved to achieve the Nation's energy goals." Delays in energy facility siting and operation are traceable to many problems, most of which could be addressed by more careful and coordinated planning(Federal Power Commission, 1975). By determining economically feasible sites for coal gasification facilities in the United States that satisfy the conditions imposed by policy decisions and social controls, it may be possible to expedite siting decisions that help to ameliorate national fuel supply problems.

A number of studies have attempted to determine feasible sites within regions of contiguous "fuel deficit" counties(see, e.g., Cirillo, et al, 1976: Van Kuiken, et al, 1977). Once these "deficit" regions are delineated, possible sites for new facilities within each area are identified and evaluated. Such analysis determines the need for facilities serving specific market areas; that is, a facility is sited to serve a previously identified fuel deficit region.

This analysis, on the other hand, assumes that fuel can be supplied to fuel deficit regions from facilities located outside the area of need. This more realistically represents the true system, at least for liquid or gaseous fuel forms, where one energy facility may serve several markets that are quite distant from each other. The strength of such an approach has been identified by Chisholm(1971: 129). Such a formulation

> can be translated into linear programming terms, since any one "market" area may be served from two or more points of supply, and each point of origin may serve more than one "market". The fact that there is an analytical technique to cope with the allocation problem is an enormous advantage.

Coal gasification facilities are chosen as the subject of study for two major reasons. First, natural gas shortages in the United States have grown to emergency proportions, and the options for augmenting gas supplies are relatively limited. The domestic natural gas supply is dangerously low, and more shortages are anticipated, with the likelihood of economic and social disruption(see, e.g., Federal Power Commission, 1972). Coal gasification is a principal domestic gaseous fuel alternative to natural gas.

Second, natural gas utilities, the prime developers of coal gasification facilities, face a plethora of problems in commercializing these new and expensive technologies. For instance, utilities have meager financial reserves compared to the major oil companies. Because of the increasing cost of such facilities(currently costing more than one billion dollars apiece), together with the relatively small increment of supply capacity added by one of them (such a facility provides no more than 10 percent of a particular utility's supply capacity) and the potential of delays in construction, coal gasification is a risky investment. Hence, no such facilities are presently commercially operating in the United States(Kash, et al, 1976: 175).

For these two reasons, among others, a methodology is useful which reduces uncertainties about the risks, costs, and benefits of different patterns of development. Furthermore, the methodology can be especially useful if it provides information about the relative profitability of potential sites and if it helps to inform decisions about the encouragement and/or regulation of coal gasification development.

Although national goals clearly call for increased domestic energy production(see, e.g., Energy Users Report, 1977b), no mechanisms now exist to insure that the requisite energy supply facilities will be sited. National plans for increasing domestic energy production rely on indirect methods such as regulations and incentives to motivate the private sector. Systematic long-range plans are formulated by private enterprise, but these are considered to be proprietary and are not publicly disclosed. Therefore, a serious lack of coordination exists in achieving stated national goals of increased domestic energy production.

Comparing "alternate scenarios" based upon different assumptions provides knowledge of the options necessary to achieve desired domestic energy development plans and the relative feasibility of different sites. If, for example, a "gaseous fuel independence" strategy is pursued, the policymaker is provided with information on what sites are repeatedly optimal under different conditions and from where the synthetic gas is most efficiently transported. Additional studies can further analyze these continually optimal sites. If these are indeed economically attractive, utilities can be encouraged to construct facilities in these "optimal" sites by such standard practices as loan guarantees, tax incentives, or other measures. As such, the methodology can provide a means of coordinating national goals with private plans and ventures.

In order to further justify the emphasis on coal gasification facilities as a worthy topic of discussion, the next chapter reviews the natural gas shortage in the United States and the potential for utilizing coal gasification facilities to ameliorate the situation. The existing natural gas supply system is briefly described so that the spatial allocation results make sense within a realistic framework. The implications of fuel supply patterns on interregional politics is briefly highlighted. The remainder of the next chapter briefly examines the potential of commercializing coal gasification facilities and their potential contributions to the nations' gaseous fuel supply.

The third chapter describes the spatial allocation model which is used as the tool to view potential synthetic gas supply systems in the United States. The formulation of the solution algorithm(Out-of-Kilter) is presented, and it is shown how the synthetic fuel supply system can be structured as a minimal cost network flow problem. This chapter also presents the data that are required to model the synthetic gas supply system in the United States.

The fourth chapter reports the results of baseline simulations which represent "ideal" cases with only technological constraints. These simulations show the siting strategies and the flows of synthetic, imported, and Alaskan gas needed to satisfy different levels of gaseous fuel demand. Comparisons are made between the different simulations.

Chapter five examines the effects of policies which may exclude certain sites from consideration in the synthetic fuel supply system. These results are compared to the earlier "ideal" cases in chapter four. The following chapter reports the results of simulations in which the attractiveness of various sites is altered by a range of circumstances. For instance, new reclamation requirements are expected to influence the siting of new coal-related energy facilities. Also evaluated in this chapter are the possibilities of other sites not considered in the earlier chapters. The differences between the minemouth and the "strip-and-ship" siting strategy are also compared.

The last chapter consolidates the results of the previous simulations by considering how different siting policies can affect the distribution of costs and benefits arising from them. The implications of alternative fuel supply systems are evaluated in terms of their cost, feasibility, and impacts on regional and national policy. The chapter concludes with specific appraisals of how best to achieve certain policy goals given the character of the emerging facility siting policy system.

Most of the data compilations and technical details are presented in the Appendices. Only that information deemed necessary for an adequate understanding of the workings of the model is provided within the text.

CHAPTER II

THE ROLE OF COAL GASIFICATION IN THE GASEOUS FUEL SUPPLY SYSTEM

Introduction

Before evaluating alternative siting strategies for coal gasification facilities in the United States, it is first desirable to appraise the need for these facilities and to consider how it has been proposed to incorporate them into the nation's gaseous fuel supply system. A brief characterization of the present gaseous fuel shortage is first presented to emphasize the critical nature of the problem. Then the current supply and demand patterns for gaseous fuel are described, and their sectional implications discussed. Next, the potential contributions of coal gasification to the system are briefly sketched. A summary of some of the problems of commercializing these facilities is also presented.

The National Gaseous Fuel Deficit

The natural gas crisis is probably the most acute fuel shortage facing the nation today. Natural gas consumption has been increasing faster than the proven reserve inventory since 1946(Federal Power Commission, 1972:2; Federal Energy

Administration, 1977:32). At current rates of consumption, approximately 12 years of natural gas reserves remain in the United States(Environmental Information Center, 1975:65).[1] Total domestic proved reserves have been steadily declining from a 1967 peak (except for a brief period when Alaskan reserves were added to the inventory) (Federal Energy Administration, 1974:89). The existence of the shortage was first felt in 1970, when curtailments of the fuel for interstate markets began(Federal Power Commission, 1975a:3). The acuteness of the severity of the problem was publicized by the natural gas crisis that hit the Northeast in the winter of 1976-77 and closed many schools, industries, and offices (Benjamin, 1977; The Norman Transcript, 1977).

The outlook for the near future is not bright as domestic natural gas production is not expected to satisfy gaseous fuel demand and imports may be difficult and undesirable to use. Expectations are that domestically produced natural gas will satisfy only 80 percent of the domestic gaseous fuel demand by 1985, requiring imports, fuel substitutions, or curtailments(Federal Power Commission, 1972:136). The potential for supplementing domestic natural gas production with overseas imports is limited because of available

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[1]The Office of Technology Assessment estimates that less than 11 years of proved reserves exist at the present levels of consumption(Office of Technology Assessment, 1977a:45).

technology and the characteristics of the resource. Controversy exists, for example, over the safety of Liquified Natural Gas (LNG) tankers and terminals (e.g., Smith, 1976; Drake and Reid, 1977; and Office of Technology Assessment, 1977) which may inhibit the rapid deployment of this supply alternative. However, based on announced and existing projects, it is expected that LNG imports can provide about 10 percent of the nation's gaseous fuel needs within ten years. If adequate pipelines are constructed, Mexican gas may also add to the supply(Oil and Gas Journal, 1977b). However, such plans contradict national plans to reduce the dependence on foreign fuels. In sum, national gas shortages are expected to increase in the future and few alternatives are available to increase the supply from foreign sources.

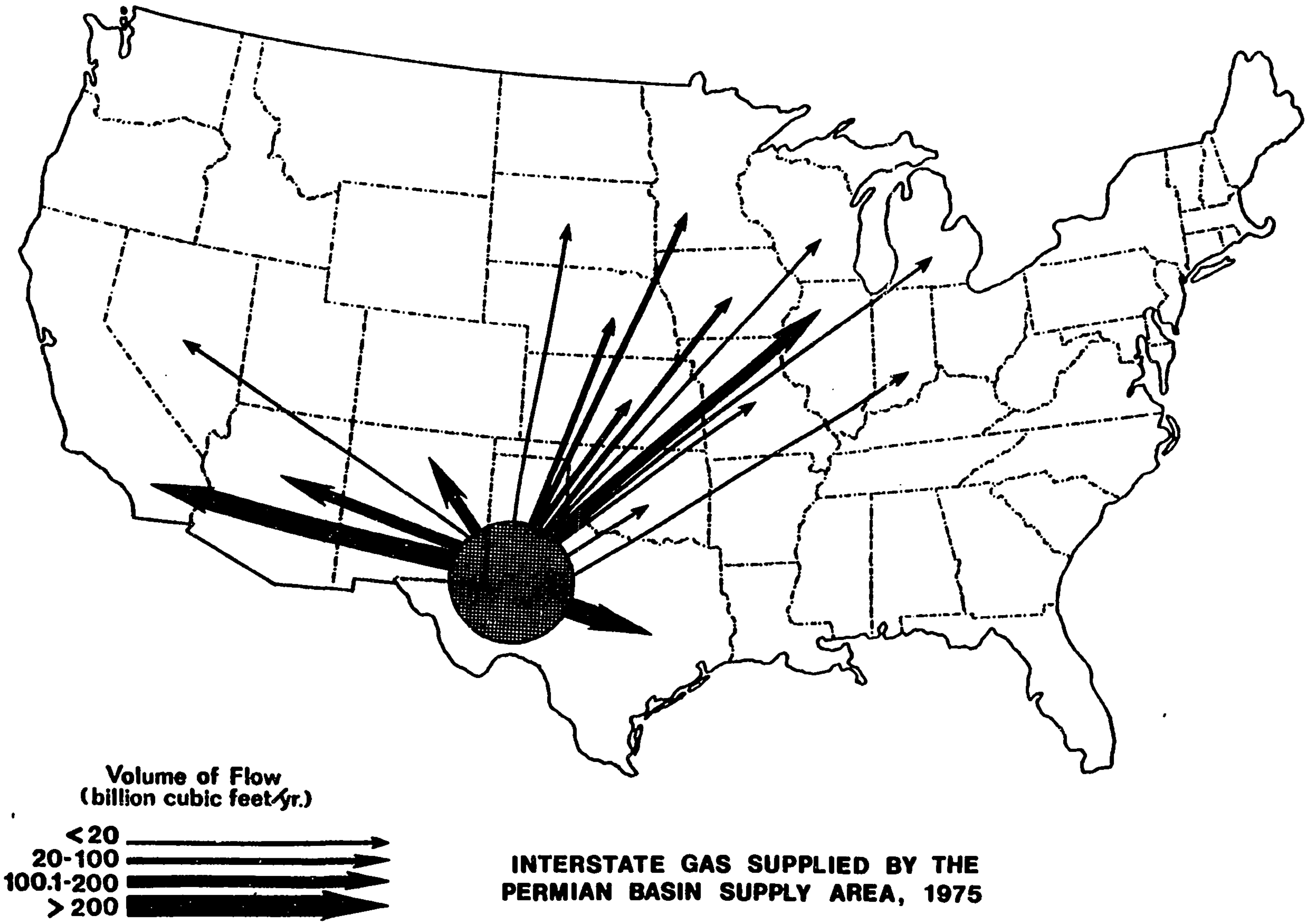
Regional Gaseous Fuel Supply/Demand Patterns

The present patterns of natural gas supply and demand must first be identified if the implications of various synthetic fuel allocation policies are to be understood, because the synthetic fuel supply system will be overlaid upon the present gas supply system, helping to alleviate deficits. The location of future coal gasification facilities will be influenced by present and future natural gas supply areas, the expected regional demand for gaseous fuels, the location and size of the interstate pipeline network, and contracted flows within that system.

Patterns of Natural Gas Production

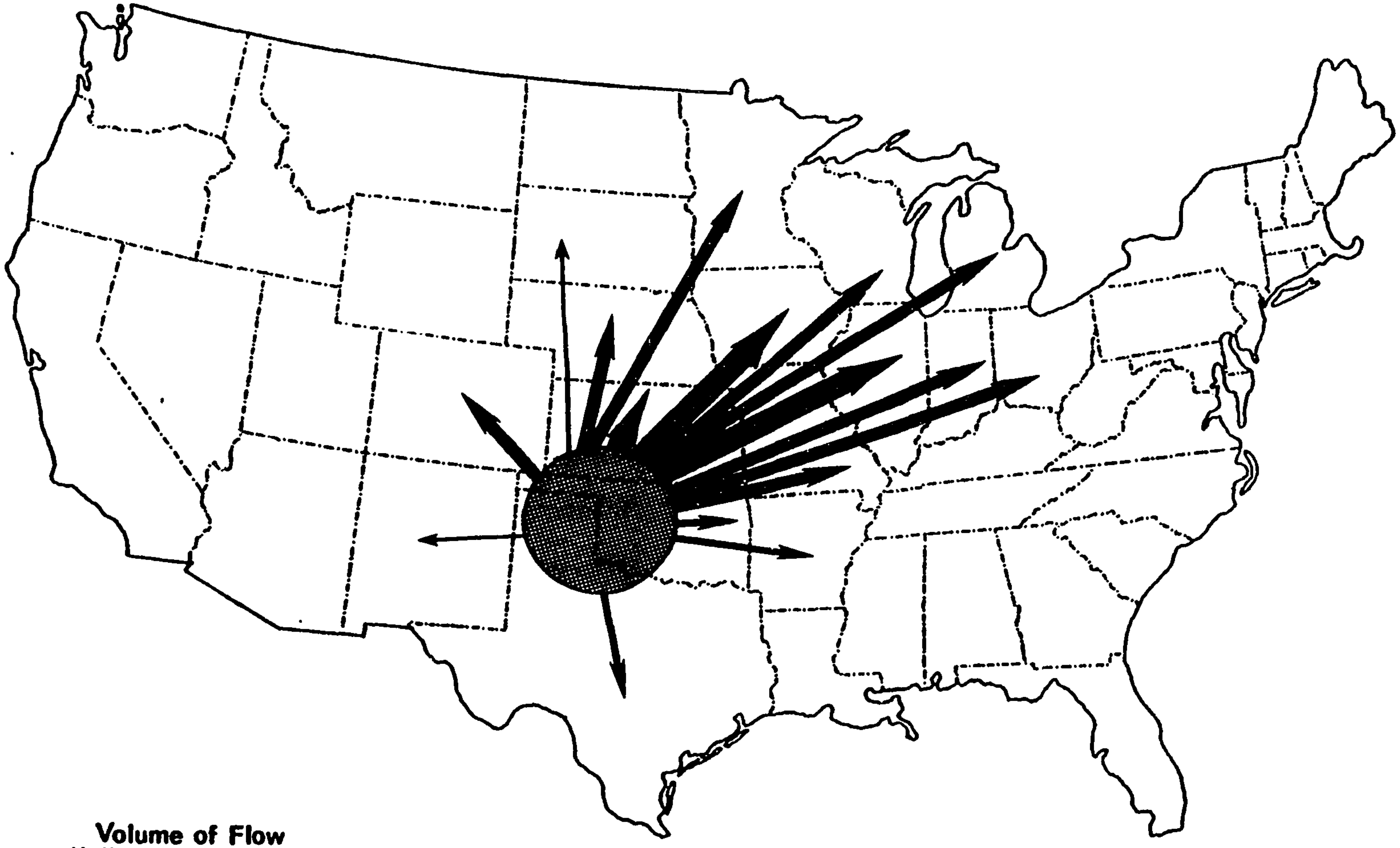
Currently, five major producing areas supply over three-fourths of the nation's natural gas: Louisiana Offshore; Southern Louisiana; Texas Gulf Coast; Permian Basin, Texas; and the Hugoton-Anadarko area(Federal Power Commission, 1977: 12). Figures 1 through 5 show the location of these areas as well as the flows of natural gas to the markets. Louisiana and Texas Gulf Coast production is largely transported to the Northeastern and Southeastern states. The Hugoton-Anadarko area supplies the Middle West, Great Plains, and Colorado. The Permian Basin production largely goes to California and the Southwest as well as to many of the Middle Western states. The overall flow of natural gas in the United States is predominately from the Southwest to the Northeast, except for the important western flows originating in the Permian Basin. The pattern of natural gas pipelines, as depicted in Figure 6, is well suited to handle this flow pattern. If new gaseous fuel source areas develop from coal gasification, the needed flows of gaseous fuels may be inconsistent with this existing pipeline infrastructure.

The regional concentration of natural gas production in the United States, combined with the recent natural gas emergencies, has stimulated sectional conflict between the southern producing states and the consuming states of the north. Only seven of the contiguous forty-eight states are net natural gas exporters: Kansas; Louisiana; New Mexico; Oklahoma; Texas; West Virginia; and Wyoming. West Virginia,



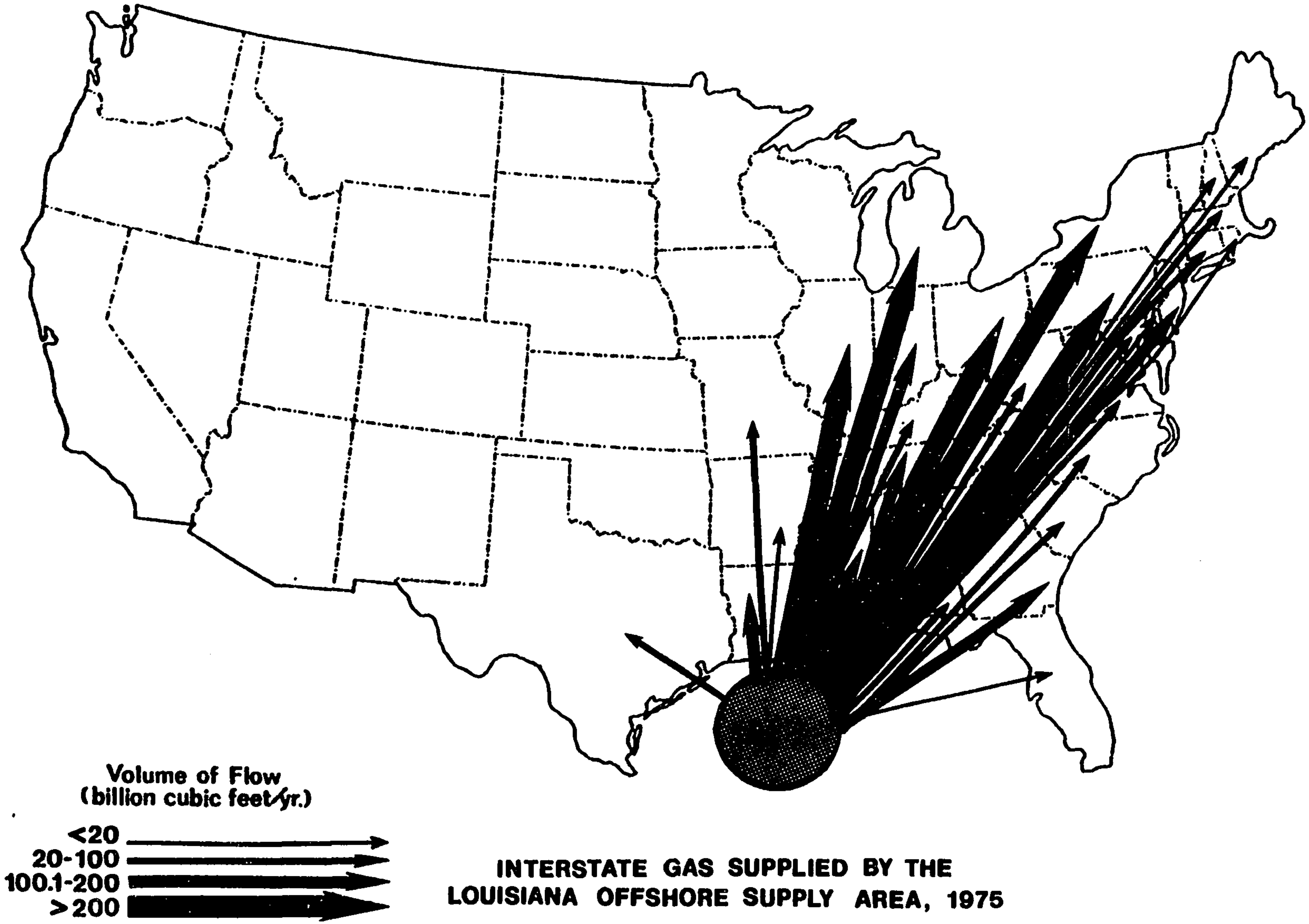
INTERSTATE GAS SUPPLIED BY THE
PERMIAN BASIN SUPPLY AREA, 1975

Figure 1



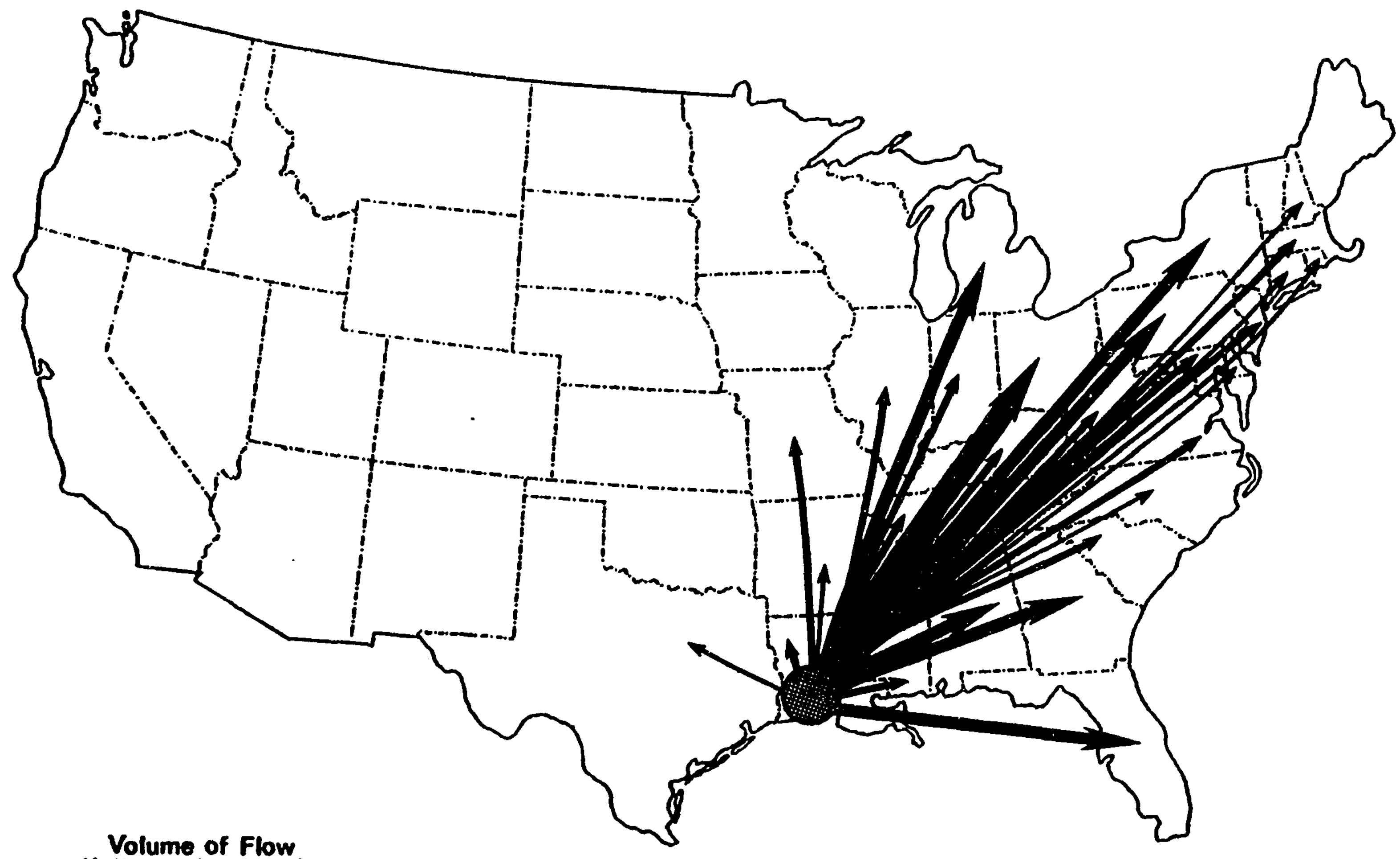
INTERSTATE GAS SUPPLIED BY THE HUGOTON-ANADARKO SUPPLY AREA, 1975

Figure 2



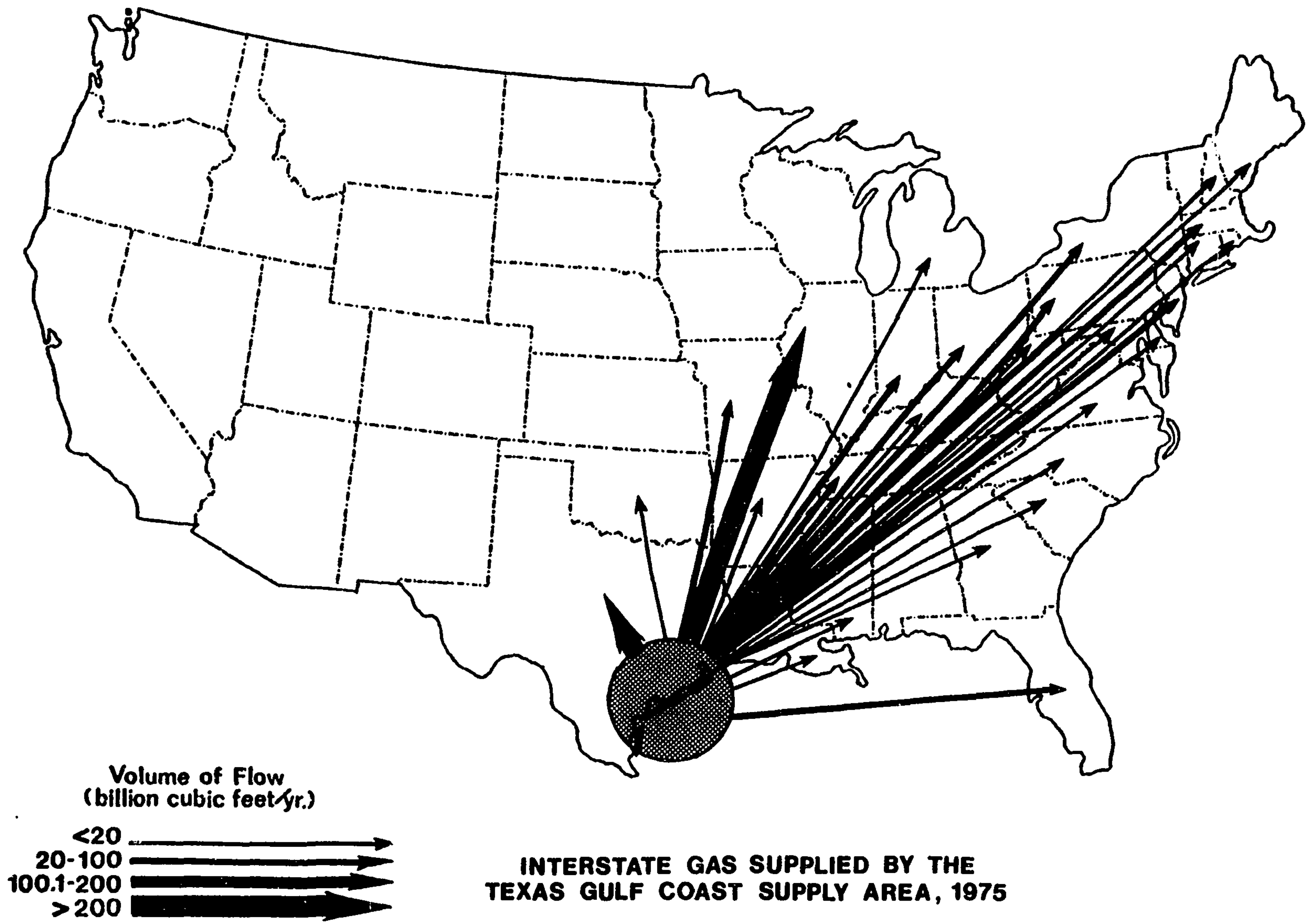
INTERSTATE GAS SUPPLIED BY THE
LOUISIANA OFFSHORE SUPPLY AREA, 1975

Figure 3



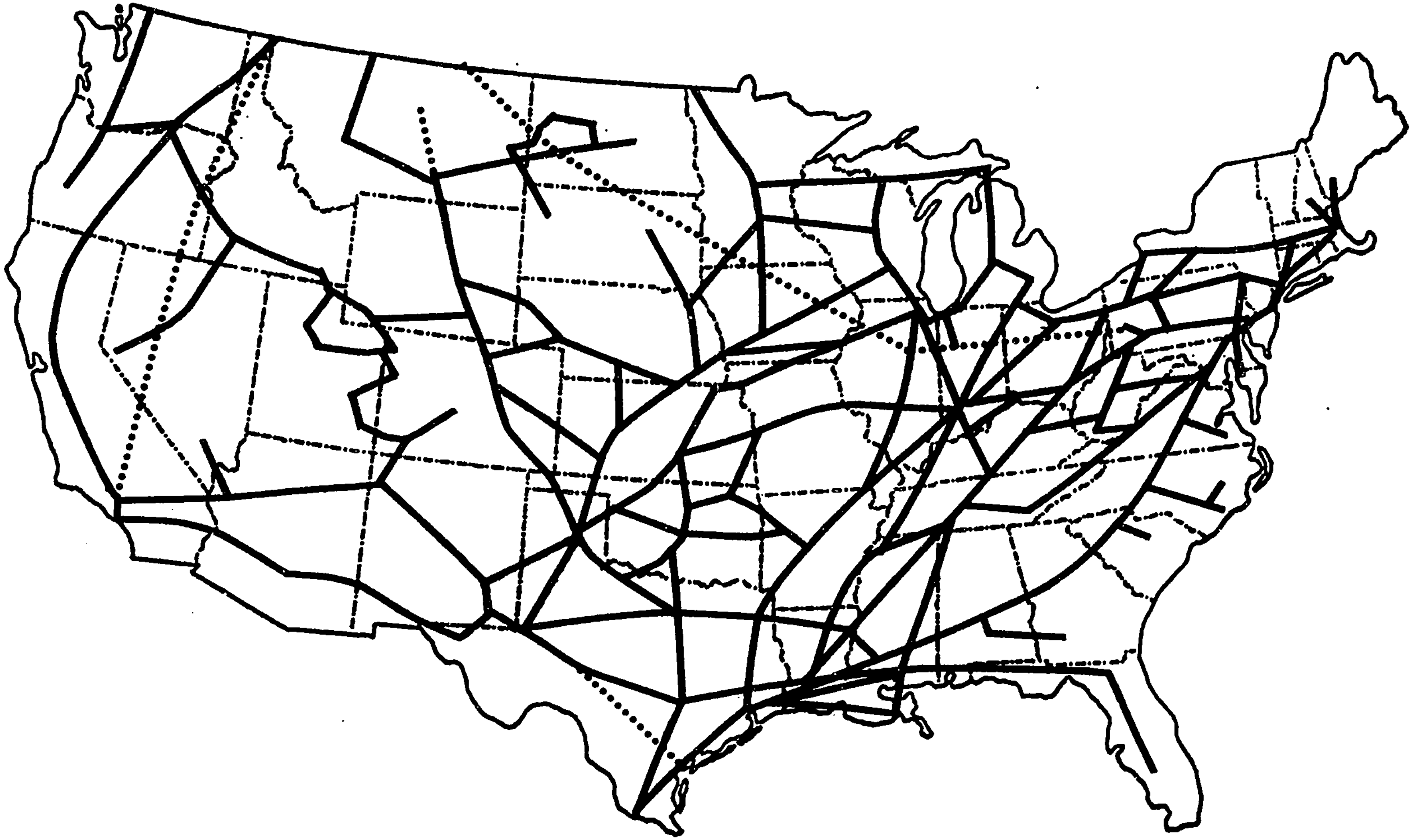
INTERSTATE GAS SUPPLIED BY THE
SOUTH LOUISIANA ONSHORE SUPPLY AREA, 1975

Figure 4



INTERSTATE GAS SUPPLIED BY THE TEXAS GULF COAST SUPPLY AREA, 1975

Figure 5



Major Natural Gas Pipelines (Generalized)

existing ———
proposed ·······

Figure 6

the only northern state among this group, barely produces more natural gas than it consumes(Federal Power Commission, 1977:12).

Recent shortages in the Northeast have led to charges and counter-charges. The producing states were accused by representatives of consuming states of "withholding supplies",[1] while spokesmen from the producing states maintained that they were being exploited by Northeastern states which had ample offshore reserves but were unwilling to accept the risks in their development.[2]

Reflecting longstanding contrasts in cultural history, social and political attitudes and institutions in these two regions are distinctly different(Elazer, 1972). This rift hampers political accommodation and interregional cooperation even in the best of times. Increased dependence of the Northern states on Southern producing areas may intensify conflicts in an era of resource scarcity.

Most of the coal gasification facilities proposed to date are to be located outside the traditional natural gas producing areas, but the existing pipeline network is not

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[1]Natural gas producers operating on federal leases in the Gulf of Mexico were suspected of withholding supplies and waiting for prices to rise. Interior Secretary Cecil D. Andrus has ordered a probe into the matter(Corrigan, 1977:324).

[2]In March, 1977, Governor Edwards of Louisiana announced plans to cutback natural gas production on state owned leases in an attempt to encourage Northeastern states to develop their offshore leases(Denver Post, 1977a).

capable of handling massive gas flows from these proposed new sites to the Northeast. Thus, even with the rapid development of gasification, the Northeast will still continue to receive gas from the Southern producing states. The new gas supplies resulting from gasification will supplement natural gas for the foreseeable future, not replace it.

Patterns of Natural Gas Consumption

Approximately one-third of all energy consumed in the United States is natural gas(Environment Information Center, Inc., 1977:106). The largest portion of this gas is used for industrial purposes where it is valued for its convenience and cleanliness. This usage is designated by federal law as a lower priority use if allocations of the resource are necessary("Emergency Natural Gas Act of 1977", P.L. 95-2, Sec.2(1)). Less than 30 percent of the total gas is consumed for residential needs, 18 percent by electric utilities and 13 percent for commercial needs(U.S. Department of the Interior, 1976:8). Residential and commercial uses are termed "high priority", meaning that during a natural gas emergency the President can order an allocation of natural gas from other uses to fulfill these needs("Emergency Natural Gas Act of 1977", P.L. 95-2, Sec.2(1)).

The pattern of natural gas consumption in the United States displays strong regional variation. As illustrated in Figure 7, the largest gas consuming states are Texas, Louisiana, California, and Illinois, respectively. The

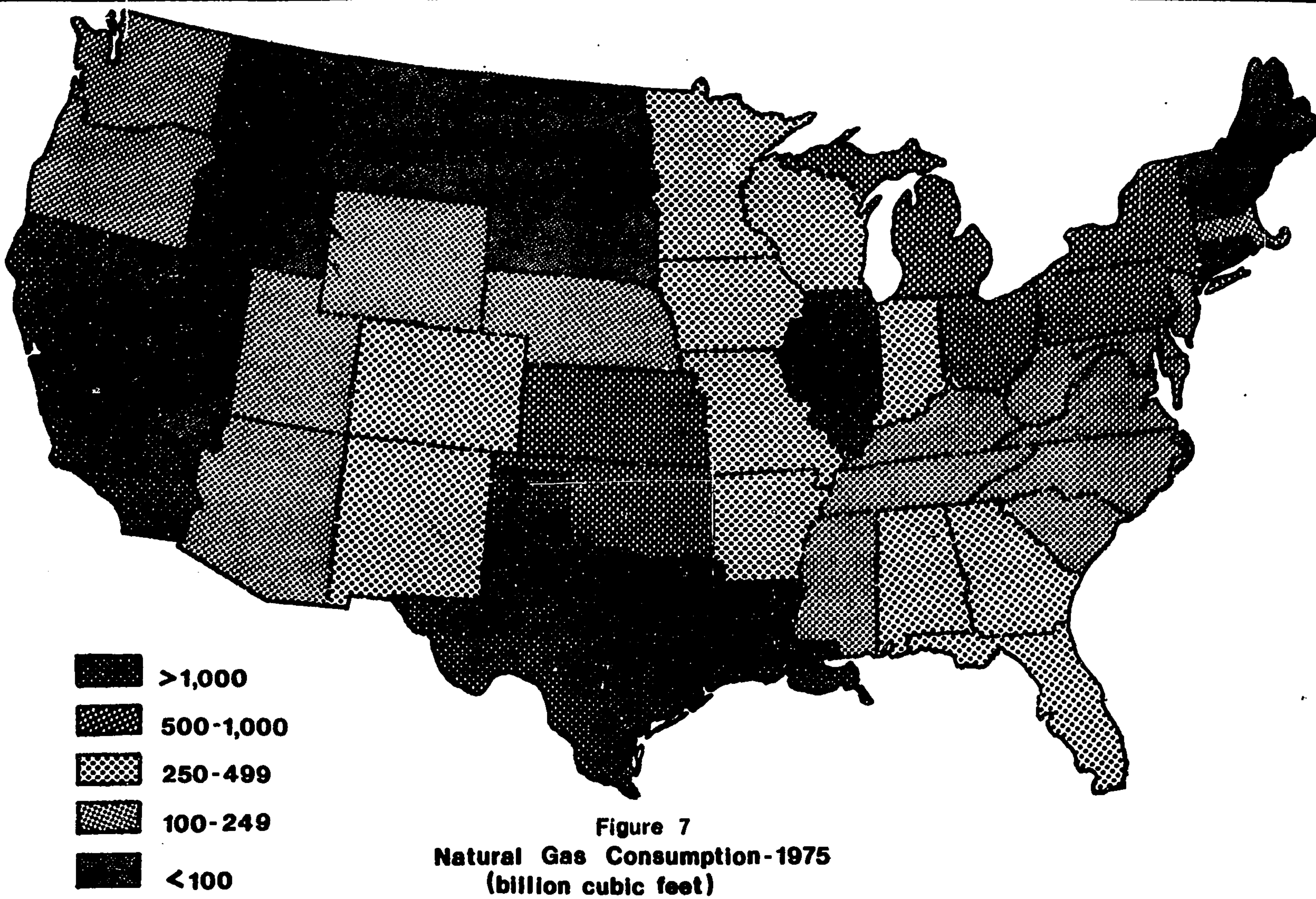

Figure 7
Natural Gas Consumption-1975
(billion cubic feet)

Source: U.S. Department of the Interior, Mineral Industry Surveys, 1975

manufacturing states of the Northeast are large gas consumers as are the large producing states of Kansas and Oklahoma. The two largest consuming states, Texas and Louisiana, use over 90 percent of their total for industrial and electric utility purposes, lower priority uses. Similar patterns exist for the other major natural gas producing states of Oklahoma, Kansas, and New Mexico.

States which are not major producers of the fuel register the largest absolute consumption for high priority residential and commercial uses(see Table 1). Almost all of the natural gas consumed in the Northeastern states goes to "high-priority" residential and commercial needs(see Table 2). Thus, the Northeastern states, although not being the major consumers of natural gas nationally, are most dependent upon the fuel for legally defined critical uses. A national allocation of natural gas during an emergency would lower consumption in the lower priority uses in the Southern producing states so that the residential and commercial needs in the Northeast could be satisfied.

Coal Gasification Potential

Coal gasification can supplement domestic natural gas supplies in the coming decades if appropriate action is soon taken to begin constructing the required facilities. Several types of gasification technologies have been unveiled. The type of gasification facility under consideration is this study is the Lurgi high-Btu(approximately 1000 Btu per thousand cubic feet(Mcf)) process which produces

Table 1: Total Natural Gas Consumed for Residential and Commercial Purposes, 1975

State	Gas Consumed[a] (in billion cubic feet)
California	864.3
Illinois	692.6
Ohio	591.8
Michigan	452.1
New York	444.4
Pennsylvania	365.5
Texas	314.1
Missouri	232.9
Indiana	231.4
Wisconsin	181.9

Table 2: Percentage of Total Gas Consumption Used for Residential and Commercial Purposes, 1975

State	Percentage Consumed[a]
Massachusetts	80.5
New York	77.0
New Jersey	74.4
Connecticut	74.2
Rhode Island	74.0
South Dakota	71.4
Maryland(D.C.)	69.4
Maine	68.9
New Hampshire	68.9
Vermont	68.9

[a]Compiled from: U.S. Department of the Interior, Mineral Industry Survey's, "Natural Gas Production and Consumption,1975," Washington, D.C.: U.S. Government Printing Office, 1976, p. 8.

gas(principally methane) of the same quality as reservoir produced natural gas.[1] Because of the high risk and uncertainties associated with these synthetic fuel projects, combined with the estimated high costs for the resulting gas, no commercially operating gasification facilities exist in the United States.

The principal appeal of developing coal gasification is the abundance of domestic coal reserves. By any calculation, United States coal reserves are massive, comprising approximately 85 percent of the nation's fossil fuel reserves.[2] Unlike the geographically concentrated pattern of major natural gas reserves, coal reserves are dispersed throughout the United States(see Table 3). The only region short of reserves is the Pacific coast states. Twenty-four of the contiguous forty-eight states produce coal commercially. North Dakota, with its vast Williston Basin lignites, has the largest known domestic reserves, followed by Illinois and Montana. Large coal reserves lie relatively close to the Northeastern and Middle Western markets.

Although coal gasification is one means of supplementing domestic gaseous fuel supply in the mid-term, its contribution is likely to be slight and the resulting fuel will be relatively expensive. Optimistic estimates of the costs

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[1]Descriptions of coal gasification processes are available in other sources(see, e.g., Science and Public Policy, 1975; Federal Energy Administration, 1976).

[2]Over 400 billion tons are known in location, quantity, quality, and are economically recoverable(Averitt, 1973:137).

Table 3: Coal Reserves Per State
(in 10^{15} Btu's)

State	Total Reserves*
Alabama	459.0
Arizona	250.3
Arkansas	31.2
Colorado	2025.6
Georgia	.2
Illinois	1435.3
Indiana	419.5
Iowa	79.1
Kansas	15.8
E. Kentucky	389.6
W. Kentucky	92.8
Michigan	2.8
Missouri	156.3
Montana	2050.9
New Mexico	632.1
N. Carolina	1.5
N. Dakota	2207.8
Ohio	471.0
Oklahoma	46.7
Oregon	.6
Pennsylvania	568.2
Pennsylvania(anthracite)	224.7
S. Dakota	14.2
Tennessee	16.0
Texas	977.7
Utah	273.9
Virginia	115.0
Washington	86.9
W. Virginia	1650.6
Wyoming	1510.6

*Assuming 50 percent recovery

Source: Battelle Pacific Northwest Laboratory, The Regional Analysis of the U.S. Electric Power Industry, Vol. 4a Coal Resources in the United States, 1975.

of high-Btu synthetic gas range from $3.03 to $4.23 per thousand cubic feet(Mcf)(Federal Energy Administration, 1976: 156). The production of synthetic gas, however, may be sufficient to prevent gaseous fuel curtailments in some areas. Also, pricing mechanisms can "roll-in" the price of synthetic gas with the price of other gas to minimize the financial impact to a particular market or utility.[1] Such a policy may require a change in federal law to make coal gasification development a national policy.

Major constraints on coal gasification implementation are: technological uncertainty; economic uncertainty; environmental impacts; water requirements; and institutional limitations(Kash, et al., 1976:163). Although it is impossible to know the exact operating characteristics of these facilities(since there is no base of experience upon which to draw), some developing firms feel that engineering and research successes warrent optimism(Kurk, 1976). In their view, economic uncertainties and risk are more of an impediment to rapid gasification development. The Federal

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[1]This concept is clearly explained by Rappaport. "If substantial production of SNG(synthetic natural gas) is to be achieved before 1990(or even after that date if prices are kept low), some way must be found to subsidize their development. In view of the regulatory apparatus already in place, a particularly appealing method consists of "rolling-in" SNG costs with regular streams of interstate gas. Rolling-in of costs means that a pipeline company adds together the total costs of all its gas sources, divides by the number of cubic feet, and charges that rate to all its customers. An incremental system would attribute specific sources to specific customers and pass costs through on that basis. The incremental system results in different prices being charged to different customers"(Rappaport, 1977:61).

Energy Administration(1976:155) noted, for example, that the

> major reason the projects have not proceeded is that the risks associated with initiating synthetic fuel projects are large compared with other investments providing an equal or higher rate of return.

In addition, the return on investment of these facilities is not great. The developing utilities, moreover, go heavily in debt to finance gasification and do not receive that much more fuel. For instance, the project sponsored by El Paso Natural Gas Company would increase the company's total capital investment by 50 percent while only adding about 6 percent to its supply capactiy(Kash, et al., 1976:171). However, the technology is attractive to some utilities as it represents another alternative to increase fuel supply that can prevent fuel curtailments in the future.[1]

Conclusion

In sum, employing coal gasification facilities can help to reduce national and regional gaseous fuel supply deficits in the United States. The financial impact of producing synthetic gas will fall to particular utilities and regions unless federal measures are taken, such as the "roll-in" pricing mechanism, to spread the cost of development more

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[1]The WESCO project, for instance, is being built to supply fuel to Southern California where gas curtailments are expected in the near future. WESCO vice-President Bixby voices the company's rationale for proceeding with the project: "The supply represented by the WESCO project is the earliest significant addition in sight for the southern California market, which would receive about three-fourths of WESCO's output"(Bixby, 1976:201).

evenly. Although there are many problems with implementing any new fuel supply technology, the barriers to coal gasification are largely not technological, but rather economic and political.

The next chapter outlines a methodology that can be useful in examining the need for gasification facilities at particular locations for alternate futures. The effect of conditions and policies that may influence their need, location, or profitability, can also be investigated through this methodology.

CHAPTER III

A SPATIAL ALLOCATION MODEL

Introduction

Although there are no satisfactory methodologies to deal analytically with all the factors that might influence siting decisions for coal gasification facilities, spatial allocation modelling provides a flexible and simple approach to evaluate a range of siting decisions. These models portray essential elements of the system of interest to policymakers so that more efficient systems can be constructed that address particular goals. Provided that a fundamental policy goal is to have a gaseous fuel supply system that incurs the lowest possible costs, spatial allocation analysis can show how the system can be made to achieve a range of important policy goals. Theoretical work has refined these models so that they more realistically portray existing conditions (see, e.g., Van Oudheusden, 1977; Whitaker, 1977; Steenbrink, 1974; and Cooper, 1972). Additional empirical work has demonstrated the usefulness of the tool in tackling real-work problems(see, e.g., King, et al., 1971; Dutton, Hinman, and Millham, 1974; Osleeb and Sheskin, 1977). Simplicity and generality are essential characteristics of the model presented. These characteristics help to bypass measurement problems and subjectiveness while broadening its applicability for other uses.

This chapter outlines the structure of a general spatial allocation model that can be useful in evaluating various policy options regarding the synthetic, imported, and natural gas supply systems. The basic spatial allocation model is a skeleton of the system upon which increasingly realistic and simultaneously occuring information and constraints can be added. These complex situations and conditions added later reflect existing conditions as well as future possibilities.

Structure of the Model

The synthetic, imported, Alaskan, and natural gas supply systems include the following components: (1) a set of coal supply points; (2) a set of natural gas producing points; (3) a set of gasification facilities; (4) a set of imported gas portals; (5) a set of gaseous fuel demand points; (6) pipeline links from the gasification facilities to the demand points; (7) rail or conveyor links from the coal supply points to the gasification facilities; and (8) pipeline links from the natural gas supply points to the demand points. Figure 8 sketches this system.

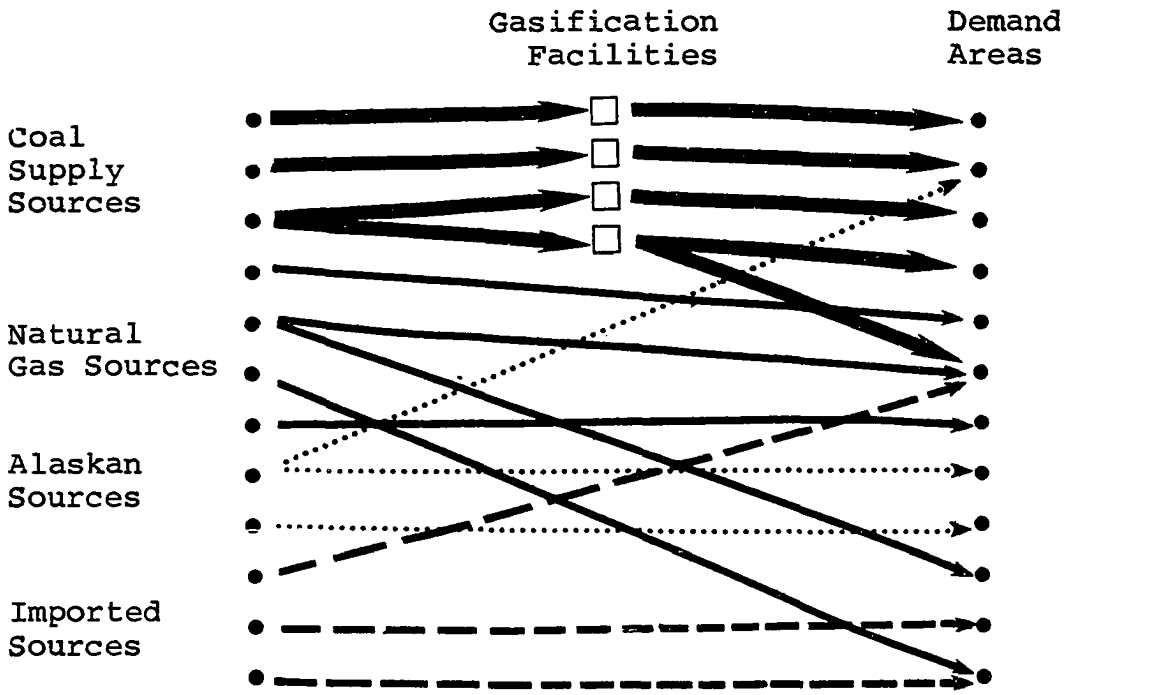

Figure 8: Structure of the Spatial Allocation Model

All the elements in the supply system have limits imposed upon them: all coal and natural gas supply areas can produce a finite amount of fuel; the rail and conveyor links from the coal sources to the gasification facilities are restricted by technological and logistical constraints on the amount of coal they can transport; the pipeline links from the gasification facilities to the markets are likewise constrained. In addition, it is assumed that an essential characteristic of the model is that demand must be satisfied. Moreover, each activity and flow through the system has costs associated with it. Each coal producing area produces different amounts and types of coal at different prices. Certain rail links are more costly to use than are others. These and other elements of the gaseous fuel supply system can be incorporated into the spatial allocation model.

The synthetic gas supply system can be viewed generically as a transshipment problem in which a primary resource is converted at an intermediary step before it can be consumed at the market(see the top portion of Figure 8). The goal of such problems is to determine which facilities should be activated, the level of activity at these facilities, and the flows between the various points so that the overall transportation and processing costs in the system can be minimized. Numerous linear programming models equipped to handle variations of such problems have sprung from the pioneering work of Beckmann and Marschak(1955).

However, the supply system of interest can be viewed more realistically as a network rather than as links connecting points in Eucledian space. The natural gas pipeline and railroad networks provide the basic infrastructure within which coal gasification facilities are to be sited. By properly formulating the problem as a network rather than its equivalent linear program, a more efficient solution can be attained by solving a minimal cost circulation problem(Durbin and Kroenke, 1967:19). Fulkerson's Out-Of-Kilter algorithm provides an efficient and general method for solving minimum cost flow problems through networks of the type described(Fulkerson, 1961; Ford and Fulkerson, 1962;

and Potts and Oliver, 1972). This algorithm can be useful in evaluating the variation in solutions as the parameters vary and is capable of efficiently solving problems of the size presented in this study. An equivalent linear programming solution to the problem would be much slower to derive. The effectiveness of the algorithm in addressing practical minimum cost flow problems for energy flows has been demonstrated in the geographical literature (King, et al., 1971; Sheskin, 1977).

The algorithm defines flows in a network which satisfy capacity restrictions on all links while satisfying the conservation of flow at all nodes. Instead of employing the iterative and costly procedures of classical transportation algorithms, the Out-Of-Kilter algorithm employs duality theory to determine the optimum flow through all links. When the optimal circulation is determined, the problem is "in-kilter" and terminates. Thus, flows, x_{ij}, are found that minimize total costs in the system:

$$\sum_i \sum_j c_{ij} x_{ij}, \qquad \text{for all } i \text{ and } j. \qquad (1)$$

These flows are found which satisfy the following constraining conditions:

$$l_{ij} \leq x_{ij} \leq u_{ij} \qquad (2)$$

Also, the conservation of flow equation must be satisfied:

$$\sum_j x_{ji} - \sum_j x_{ij} = 0, \quad \text{for all } i \qquad (3)$$

where:

c_{ij} = the cost of one unit of flow from i to j,

l_{ij} = the lower bound on the amount of flow from i to j,

u_{ij} = the upper bound on the amount of flow from i to j,

x_{ij} = the quantity of flow from i to j.

The algorithm determines a set of flows through the links that minimizes total costs; delivers the amount of gaseous fuel demanded at each market; converts no more or less coal to gas than the gasification facilities are capable of handling; transports no more fuel than each link's capacity; and produces no more coal than a particular supply area is capable of providing. The solutions identify the amount of fuel transported, and the total costs of the system. The algorithm continues until the problem is shown to be either optimal or infeasible.

Because the unit movement costs, c_{ij}, represent the costs incurred to move a unit of coal or gas from node i to node j, additional artificial nodes must be added to incorporate operation costs at the gasification facilities. The c_{ij} incurred along these links represent the costs of converting one unit of coal to synthetic gas. The l_{ij} and u_{ij}, representing the lower and upper limits of flow for any link, can be adjusted to simulate certain decisions regarding the use of coal producing areas, rail links, gasification facilities, or pipeline links. Controlling the l_{ij} for particular links can allow specific minimum demand levels for certain nodes to be specified. Equating u_{ij} to zero for certain links can effectively eliminate certain facilities or transport lines from consideration. Therefore, different existing conditions can be simulated by adjusting the bounds, costs, and the input data.

Input Data

This section describes the data that are employed in the model. Like all simplifications of reality, the model portrays key elements of the system so that changes in it can be portrayed and analyzed. Although it is not possible to include all the relevant information into such a generalized fromework, the salient characteristics of it are effectively portrayed making the model a useful tool in evaluating gasification facility siting options and alternative fuel supply options. Of particular note is the fact that this formulation does not consider the fixed costs incurred in opening a particular facility. Marks(1969) has extended the Out-Of-Kilter algorithm to consider these costs. However, the application of this model to the present problem does not appear fruitful. First, available data on the fixed costs for opening coal gasification facilities does not indicate spatial variations. Although intuitively such variation should exist, modeling it may add another level of abstraction. Second, the aim of the model is to provide normative solutions for a particular future year, not to model a strategy for sequentially siting these new facilities. For such purposes, the addition of fixed-costs is not essential.

Coal Resource Data

The coal supply data used in the model were computed by evaluating the total Btu value of coal reserves per state. The specific location of that supply was derived by determining the centroid of the Btu-weighted coal reserves in each state, based on county reserve data. These data were compiled from a Battelle(1975) study which calculated the coal reserves in each county in the United States by ton and Btu. In Kentucky and Pennsylvania two centroids are used since each of these states have two separate large coal fields with different coal characteristics. A potential supply figure is calculated for each potential coal producing state, on estimates made by Hittman Associates(1974) on the life of a modern coal mine. This information provides the basis upon which to evaluate the resource base for particular gasification facilities. These calculations and tables are found in Appendix A.

Natural Gas Supplies

Natural gas supply data for current years are available from Federal Power Commission(1977) sources which show the interstate flows of natural gas in the United States and per state consumption levels. All simulations in this study assume that domestic natural gas production will continue at the present level of approximately 20 trillion cubic feet(tcf) per year. Despite much publicity during the past few years over production declines, it appears that domestic production will increase if the interstate prices are permitted to rise. For instance, when the Federal Power Commission raised interstate gas prices from 52 cents per thousand cubic feet(Mcf) to $1.42 per Mcf in July 1976, there was an immediate surge in new drilling activity and an increase in domestic gas reserves(Falternayer, 1977:166). The Carter Administration maintains that supply elasticity practically disappears after $1.75 per Mcf and that further price increases will bring negligible returns (Falternayer, 1977:109; Energy Users Report, 1977a:28). Since it is not possible to predict what the allowable interstate gas price ceiling will be, the assumption employed here is that domestic production will remain at 20 tcf at $1.55 per Mcf. The simulations will then attempt to show ways in which deficits between natural gas supplies and natural gas demand can be most effectively eliminated.

Coal Gasification Facilities

Since there are no commercially operating coal gasification facilities in the United States, information on their location, requirements, costs, and impacts is based upon engineering estimates and publicly announced plans. Numerous reports are available which provide information on these technologies. For purposes of consistency and comparability, all facilities are assumed to be a standard size 250 mmcf/day Lurgi gasification plant. These facilities are generally assumed to be the most promising gasification technology and many are operating in other countries.[1] The average cost per thousand cubic feet of synthetic gas produced from $6.00 per ton coal is approximately $0.67(Science and Public Policy, 1975:1-12). The coal processing efficiency of the facilities is expected to average about 60 percent(Science and Public Policy, 1975:1-106). The model employed, however, will assume that coal will cost $8.00 per ton. These details and other information concerning the costs of the facilities are discussed in the next chapter.

The locations of the facilities used in the preliminary models are taken from Bureau of Mines information showing the

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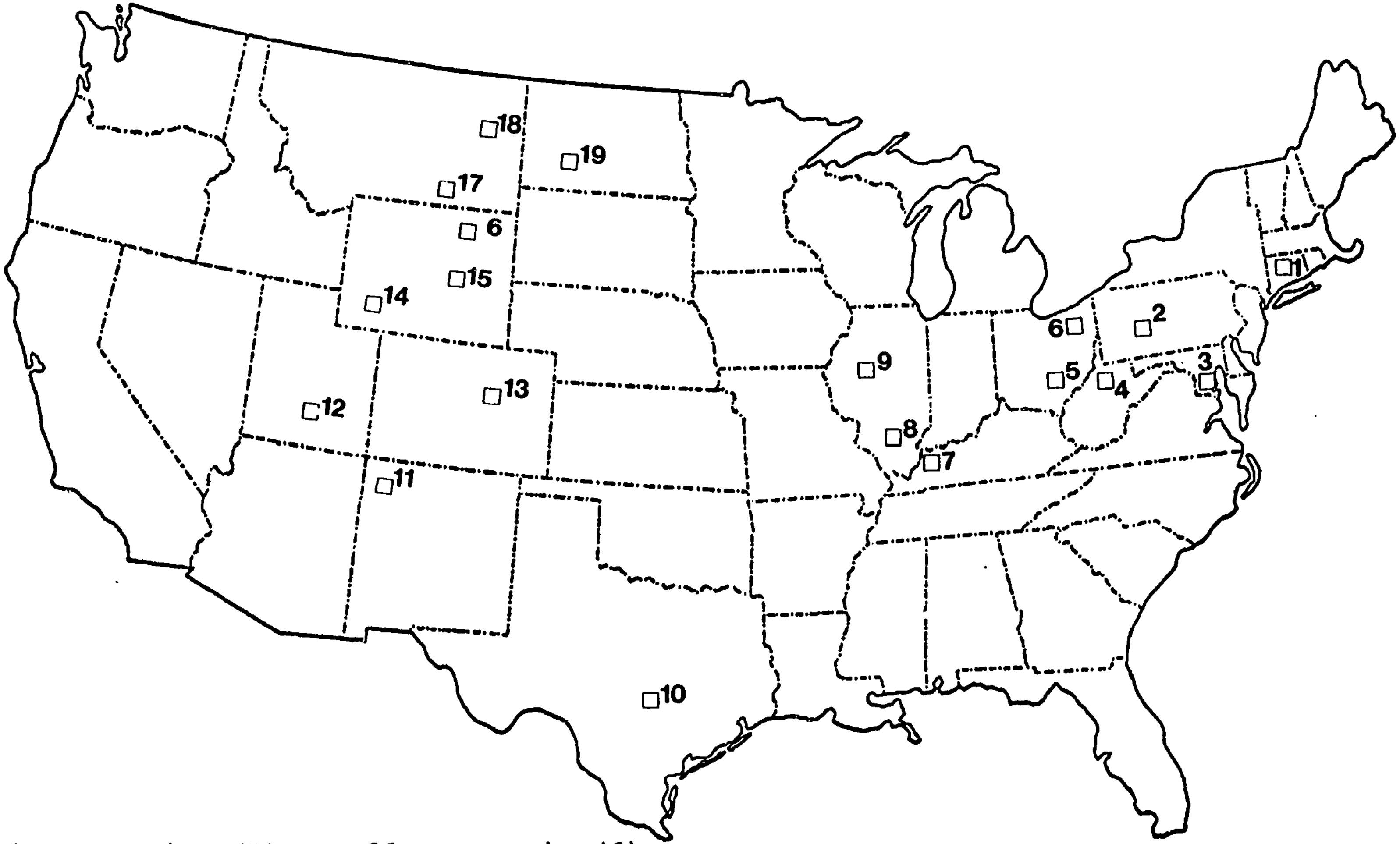
[1]Eric H. Reichl, for instance, the President of Conoco Coal Development Corporation, advocates the use of Lurgi gasifiers. Speaking at the 4th annual Energy Technology Conference and Exposition, he "...strongly suggested that instead of pursuing new systems for coal gasification with cost and risk involved, the Lurgi system should and can be utilized, as is being done in other nations. He said that R&D programs have already shown the basic soundness of the Lurgi process, and that it is well demonstrated, including the gas cleanup and methane production steps(Nolden, 1977:95).

locations of announced coal gasification facilities in the United States(Corsentino, 1976; U.S. Department of the Interior, 1976a). It is assumed that facilities not yet announced will be unable to produce gas by 1985. However, other sites will be considered in later simulations to show the potential of considering alternative sites. The sites for the facilities used in the preliminary simulations are shown in Figure 9. All of these except the Connecticut, Baltimore, and Northeastern Ohio facilities are minemouth operations. These three are assumed to recieve coal by unit-train from the nearest coal source. The number of announced facilities at each site is also indicated in Figure 9.

Links

Three transport modes are considered in the synthetic and natural gas supply system: railroads, conveyers, and pipelines. Most new coal gasification facilities proposed in the United States are minemouth facilities and will not require long distance rail transport input(Corsentino, 1976; U.S. Department of the Interior, 1976a). However, these long distance rail links are not excluded from the study entirely since simulations on "market-oriented" gasification location patterns are also considered.

Coal transport rates are considerably higher than shipments of equivalent gaseous energy through pipelines. Since the



1=Connecticut(1)
2=Pennsylvania(2)
3=Baltimore(1)
4=West Virginia(2)
5=S.E. Ohio(1)
6=N.E. Ohio(1)
7=W. Kentucky(1)
8=S. Illinois(4)
9=C. Illinois(1)
10=Texas(1)
11=New Mexico(6)
12=Kaiparowits(3)
13=Colorado(1)
14=S.W. Wyoming(1)
15=C. Wyoming(1)
16=N.E. Wyoming(5)
17=S.E. Montana(4)
18=N.E. Montana(2)
19=North Dakota(12)

Figure 9: Announced Coal Gasification Facilities

model is not considering alternatives which call for the construction of new long distance rail or pipeline links (except for those that have already been proposed), only the operating costs of the two modes are evaluated. Interstate Commerce Commission data show(1976) that long distance (greater than 300 miles) coal transport rates vary considerably. Similar variation exists in the cost of transporting gaseous fuel by pipeline. An FEA report(Federal Energy Administration,1974b:v-32)listing selected natural gas pipeline tariffs showed costs varying from 83 million Btu per dollar to 4.3 million Btu per dollar. These FEA data were modeled by the Stanford Research Institute(Stanford Research Institute, 1975:VI-4) to derive costs for standard high Btu gas pipelines. Their estimate placed operating costs of western-based unit trains as 8.8 times greater than high-Btu gas pipelines over a 1000-mile route. For eastern coal, the operating cost of a unit train was 6.2 times greater than a high-Btu gas pipeline for 1000 miles. As shown in the next chapter, a rate of 1 cent per ton mile was chosen for coal transport throughout the country. The Stanford data provided transport costs for high-Btu pipelines.

Demand

Because of the long lead time needed to construct these facilities, it is necessary to study a resource allocation problem for a time at least five years in the future. Hence, the simulations use 1985 as the year of study. A problem is to derive reasonable estimates of demand for that year. Long-range forecasts for natural gas demand in the United States are highly uncertain for at least two major reasons. First, changes in the international oil market can alter the demand for natural gas and its price. Second, the price elasticity of demand is not known as the price of interstate gas has been regulated by the federal government. There have been two distinct markets for gas in the United States, the controlled interstate market and the unregulated intrastate markets. It is difficult to transfer the characteristics of the intrastate market to the interstate market.

The simulations examine the supply system for a high-demand and a low-demand case so that a wider range of alternatives can be considered. Also, the study is not too closely tied to one forecast which may be outdated in a few years. The Ford Foundation's Energy Policy Project Study(1974) and FEA's National Energy Outlook(1976) were consulted to provide high and low gaseous demand forecasts for 1985. The Ford Foundation projected energy demand for multiple scenarios. The forecast utilized in this study is the "Technical Fix" scenario which provides the higher 1985 demand estimate. This scenario assumes that energy saving technologies are implemented to reduce the demand for fuel, but the implementation of these systems takes time. Beginning slowly and gathering momentum, the reduction of gaseous fuel demand is slight in 1985 while quite dramatic for the year 2000. The 1985 gaseous fuel demand estimated by this scenario is 32.36 tcf(Ford Foundation, 1974:502). The 1985 FEA estimates placing demand at 23.4 tcf(Federal Energy Administration, 1976:129) provides the lower level for use in the study.

Given the aggregate demands for gaseous fuels, the next step is to disaggregate the demand among the 48 contiguous states. This can be done in several ways, none of which can hope to accurately portray the true situation. The method used in the preliminary model is to simply divide the 1985 national forecasts among the 48 states according to the percentage of that fuel used by each state in recent years. This disaggregation is shown in Appendix B.

CHAPTER IV

PRELIMINARY SPATIAL ALLOCATION RESULTS

Introduction

This chapter reports the results of the spatial allocation simulations which are not constrained by legal, environmental, and political considerations. These simulations represent some of the "ideal" cases for certain existing conditions in the sense that they show how the maximum amount of synthetic fuel can be supplied at the least cost. The costs and configurations of later simulations in which parameters vary and constraints are added are compared to these preliminary results so that the consequences of certain policies can be discerned. The only constraints placed upon the simulations reported in this chapter are technologically derived bounds.

Although the spatial allocation model has been structured to include natural gas allocations, the only flows investigated in this study are those of synthetic, Alaskan, and imported gas. It is assumed that the present natural gas flows visulized in Figures 1 through 5 continue through 1985. The additional gaseous fuels needed to satisfy forecasted 1985 gaseous fuel deficits are examined here. For instance, the 1975 flow of

218 billion cubic feet of natural gas from Louisiana to Alabama is assumed to continue through 1985(Federal Power Commission, 1977:13). Additional fuel needed by that state must be satisfied by increased gaseous fuel production elsewhere.

Spatial Allocation Simulations

Specific information from the simulations include: (1) the "best" location and output of gasification facilities to employ for certain assumed conditions; (2) flows of synthetic, Alaskan, and imported gas; (3) estimates of the price of synthetic gas produced from the activated facilities; (4) estimates of the rolled-in price of gas under different conditions; and (5) the total cost of the entire synthetic, Alaskan, and imported gas supply system.

The simulations reported in this chapter utilize both FEA's and the Ford Foundation's 1985 demand estimates, although most of the reported results stem from the former. Since a national policy is to reduce foreign fuel imports, the simulations reported first are those using mostly domestically produced fuel to satisfy the deficit between estimated natural gas production and gaseous fuel demand.

For the FEA demand forecast, 3.064 trillion cubic feet(tcf) of gas must be supplied from coal gasification facilities, Alaskan gas, imported gas, or some combination thereof. The amount of Alaskan and imported gas added into the system is derived from FEA(1976:150) estimates which note that "...the lower 48 could be receiving 0.8 to 1.2 tcf/yr of Prudhoe Bay gas by 1985--at an estimated cost of \$2.50 to \$3.00 per Mcf including transportation to U.S. borders." The simulations reported assume that up to 1 tcf of Alaskan gas could be provided at \$3.00 per Mcf via the Alcan pipeline route.[1] Figures for imported LNG were also derived from FEA which presented three estimates on the amount of LNG which could be supplied to the U.S. by 1985. The first and lowest case says that 0.4 tcf of gas can be supplied by that date. The third and highest case estimates that just over 2 tcf/yr can be provided(FEA, 1976:152). FEA also estimated that the price of the gas would be approximately \$1.30 per Mcf. Other sources, however, note that LNG would sell for \$2.00 per Mcf (Oil and Gas Journal, 1977a). These estimates are employed here. For simplicity, the \$2.00 per Mcf price is labeled "expensive" while the \$1.30 per Mcf price is referred to as "inexpensive".

After the FEA document was published, the Mexican Government announced that is was prepared to sell natural gas from its Gulf of Mexico fields if pipelines to the United States were constructed. Pemex, the Mexican Government's oil company, notes that 730 billion cubic feet of gas a year can be supplied to the United States by 1981(Oil and Gas Journal, 1977b:64). The proposed pipeline route will follow the Mexican

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[1]Indications are that this route will be chosen to deliver Alaskan gas to the contiguous United States(Energy Users Reports, 1977).

east coast to link into South Texas transmission lines. Since these additional imports were unforeseen when the FEA report was published, additional simulations were conducted including the possible inclusion of Mexican gas. The price of Mexican imports are considered to be $2.00 per Mcf.[1] Table 4 lists eight possible imported gas scenarios, which comprise four possible importation volume scenarios combined with the different prices of LNG. These labels are used throughout the description of the simulations. The preliminary FEA simulations examined in this chapter are listed in Table 5. These are discussed in turn.

Simulation 1: High, Inexpensive Imports plus Alaskan Gas

The first simulation assumes that up to 2 tcf of imported LNG selling at $1.30 per Mcf, one tcf of Alaskan gas selling at $3.00 per Mcf, and 730 billion cubic feet of Mexican gas selling at $2.00 per Mcf can be added to help relieve national gaseous fuel deficits. The optimum solution to this simulation does not contain any gasification facilities because imports and Alaskan gas are sufficiently abundant and inexpensive to provide all additional gaseous fuel needs not provided by domestic natural gas production. If the Alaskan and imported gas costs are rolled-in to the price of domestically produced natural gas selling at $1.55 per Mcf, the combined price to the consumers would be approximately $1.57 per Mcf. Other-

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[1]The average price paid for natural gas from Mexico was $2.02 per Mcf in January, 1977 (Energy Users Reports, 1977).

Table 4: Fuel Importation Scenarios

IMPORTED GAS SCENARIOS (Each of the four importation levels can be matched to the two price levels for LNG)	
High:	$\leq$ 2 tcf LNG plus $\leq$ .73 tcf Mexican
High Medium:	$\leq$ 2 tcf LNG
Low Medium:	$\leq$ .4 tcf LNG plus $\leq$ .73 tcf Mexican
Low:	$\leq$ .4 tcf LNG
Prices:	Inexpensive: @$1.30 per Mcf
	Expensive: @$2.00 per Mcf

wise, certain areas of the country would be forced to pay higher prices for gaseous fuel corresponding to different delivery prices of the commodity. Interestingly, the optimum solution to this simulation only uses one-third of the available Alaskan gas supplies. According to this simulation, impending natural gas shortages do not seem inevitable and the need to construct gasification facilities does not seem urgent.

Simulation 2: High Expensive Imports plus Alaskan Gas

The second simulation employs the same conditions as the first except that the price of LNG is assumed to be $2.00 per Mcf instead of $1.30 per Mcf. The flow pattern with this additional modification is essentially the same as the previous case with the price of rolled-in gas rising to $1.62 per Mcf. Again, no coal gasification facilities are employed.

Table 5: FEA-Based Preliminary Simulations

	Imported Gas								Alaskan Gas
	Inexpensive				Expensive				
	High	High-Med	Low-Med	Low	High	High-Med	Low	Low-Med	
1. High Inexpensive Imports plus Alaskan	X								X
2. High Expensive Imports plus Alaskan					X				X
3. High Med Inexpensive Imports plus Alaskan		X							X
4. High Med Expensive imports plus Alaskan						X			X
5. Low Med Inexpensive Imports plus Alaskan			X						X
6. Low Inexpensive Imports plus Alaskan				X					X
7. "Gaseous Fuel Independence"									

Med=medium

Simulation 3: High Medium Inexpensive Imports plus Alaskan Gas

The third simulation assumes the same conditions as the first except that no Mexican gas is imported. The flows of synthetic, Alaskan, and imported gas for this simulation are shown in Figure 10. Without the importation of Mexican gas, it is economical to site a coal gasification facility in Texas. The price of the synthetic gas from this facility is approximately $3.18 per Mcf, demonstrating the need for the rolling-in of prices. The remaining deficit areas of the country can be effectively served by Alaskan and LNG. The rolled-in price of gas for the nation comes to approximately $1.60 per Mcf. The Texas gasification facility serves intrastate demand. Intrastate gas sales are not subject to federal regulation and can reflect market conditions.[1] Therefore, if a strong market exists in that state, the synthetic gas from the Texas facility can be sold locally at the higher price.

Simulation 4: High Medium Expensive Imports plus Alaskan

This simulation views the same situation as simulation 3 except that the price of LNG is taken to be $2.00 per Mcf. The flow pattern for this simulation is essentially the same as the previous case with the Texas gasification facility the only synthetic gas producer in the nation. By increasing the price of LNG, the rolled-in price of gas experiences a 7 cent per Mcf increase to sell at $1.67 per Mcf.

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[1]Texas has a strong intrastate gas market and gas prices in the state hover around $2.00 per Mcf(see, Faltermayer, 1977:168)

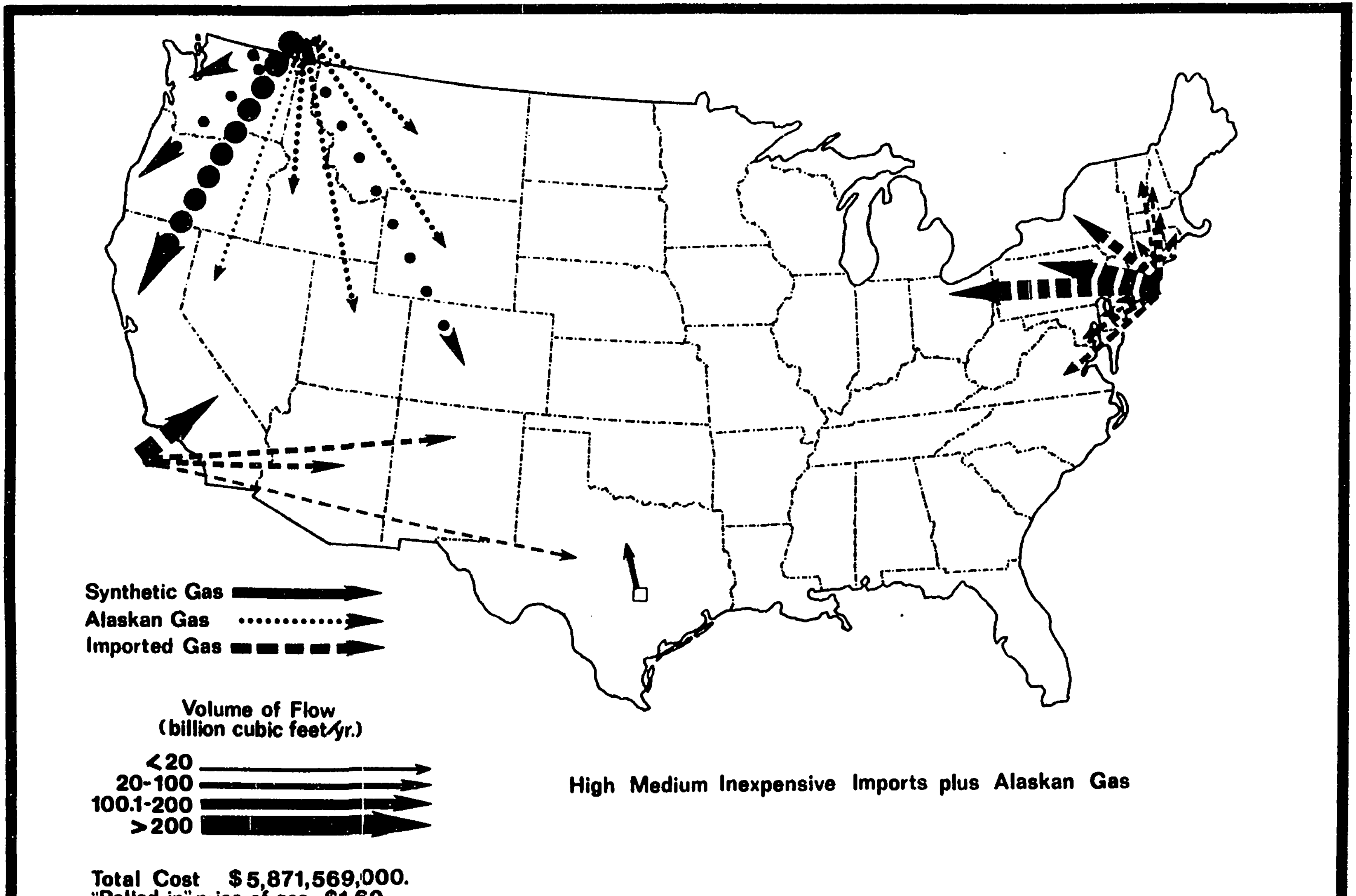

Synthetic Gas
Alaskan Gas
Imported Gas
Volume of Flow
(billion cubic feet/yr.)
<20
20-100
100.1-200
>200
High Medium Inexpensive Imports plus Alaskan Gas
Total Cost $5,871,569,000.
"Rolled-in" price of gas $1.60

Figure 10

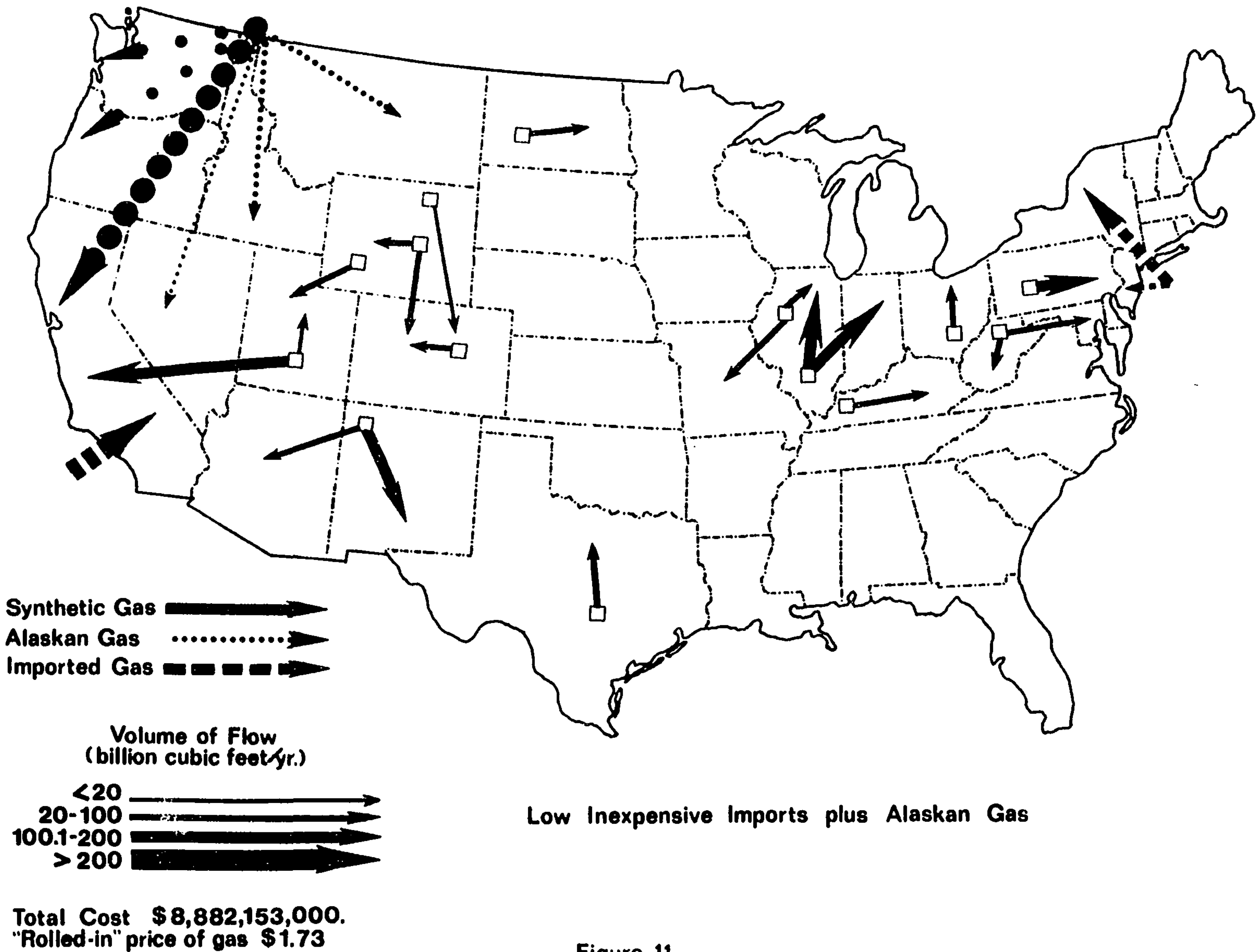
Simulation 5: Low Medium Inexpensive Imports Plus Alaskan

As shown in Table 5, this simulation is the same as simulation 1 except that LNG imports are restricted to 400 billion cubic feet per year. No gasification facility sites are utilized in the optimal solution. The resulting price of rolled-in gas is approximately $1.69 per Mcf.

Simulation 6: Low Inexpensive Imports plus Alaskan

Simulation 6 also considers the possibilities when LNG imports are restricted to 400 billion cubic feet, Alaskan gas can not exceed one trillion cubic feet, and no Mexican imports are added. Figure 11 illustrates the flows of synthetic, Alaskan, and imported gas within the United States for this case. Fourteen of the possible nineteen gasification sites are utilized in the optimal solution. Synthetic gas supplies 1.664 tcf per year, primarily to intrastate markets. The rolled-in price of gas becomes approximately $1.73 per Mcf.

As shown in Figure 11, only one of the seven Rocky Mountain-Northern Great Plains facilities serves states outside that region. The exception is the Southern Utah facility which provides 139 billion cubic feet per year to California. This lack of interregional flow from the Rocky Mountain-Northern Great Plains region counters the view that the West must become an "energy colony" of the rest of the nation(for other energy supplies, such as uranium or oil shale, this may be so).



Low Inexpensive Imports plus Alaskan Gas

Figure 11

Simulation 7: "Gaseous Fuel Independence"

This simulation represents the "gaseous fuel independence" scenario since gaseous fuel demand must be satisfied without any imported or Alaskan gas. As noted in the previous chapter, Alaskan gas is excluded from this simulation since that supply is assumed to be interruptible as it passes through Canadian territory. Synthetic fuels alone could provide the necessary fuel to supplement domestically produced natural gas to meet the 1985 gaseous fuel demand estimated by FEA. Figure 12 depicts the synthetic fuel supply system to optimally meet this condition. Fifteen of the potential nineteen facility sites must be utilized. The synthetic gas would cost approximately $3.21 per Mcf while adding 3.064 tcf of fuel to the domestic production. Rolling-in the cost of the synthetic gas into the price of other domestically produced natural gas results in a national price of $1.77 per Mcf.

It is expensive to achieve this goal. For instance, a policy decision to follow this plan would require approximately $4.6 billion more for gas greater than simulation 1 which relied heavily upon imported gas. Therefore, achieving gaseous fuel independence is technically possible at much additional cost. This additional expense, though, may be more apparent than real as domestic investments for the requisite facilities and associated mines and infrastructure would create more jobs and might help to balance the national budget. However, the environmental impacts of such a policy also

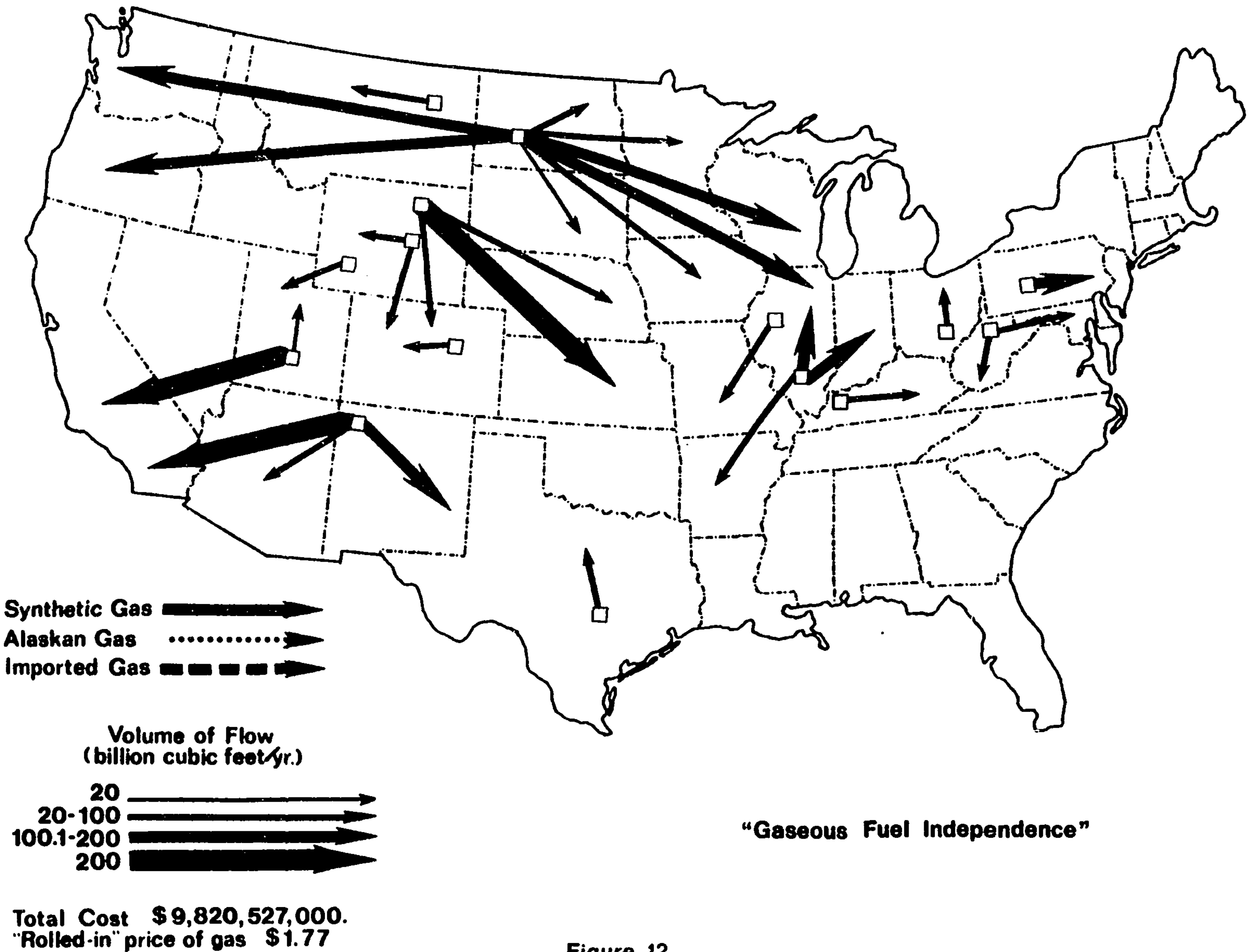

Synthetic Gas
Alaskan Gas
Imported Gas
Volume of Flow
(billion cubic feet/yr.)
20
20-100
100.1-200
200
"Gaseous Fuel Independence"
Total Cost $9,820,527,000.
"Rolled-in" price of gas $1.77

Figure 12

would increase within the United States much more so than if an import based policy was pursued.

It is also necessary that there be interregional flows of synthetic gas to attain gaseous fuel independence. Facilities in the Rocky Mountain-Northern Great Plains states must export large volumes of synthetic gas to the West Coast and the Upper Midwest. This could stimulate interregional rivalries as the consuming areas would not be subject to the noxious characteristics of coal mining and conversion. Siting delays could occur if conflicts arose at some gasification locations. The Rocky Mountain-Northern Great Plains states may not be prepared to make a regional sacrifice of their resources and quality of life so that a national goal of energy independence can be achieved. Such considerations are given more emphasis later.

Ford Foundation Forecast-Based Simulation

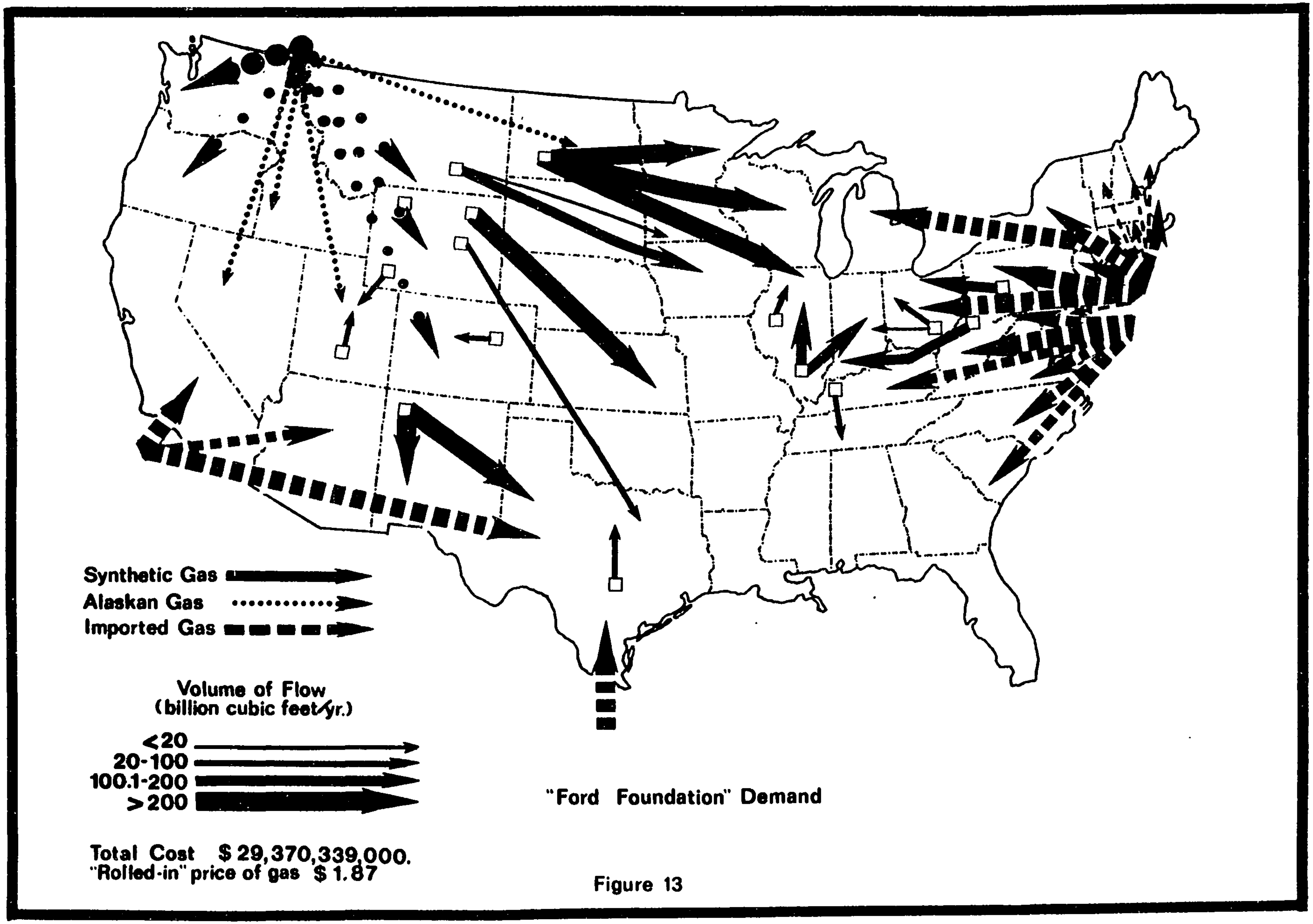
A simulation was conducted to determine methods of meeting the gaseous fuel demand of 32.36 tcf estimated by the Ford Foundation's "technical fix" scenario. "Gaseous fuel independence" can not be attained in this case as the potential synthetic gas of 4.1 tcf is unable to eliminate the national gaseous fuel deficit of 12.02 tcf per year. Gaseous fuel demand can not be attained using the information provided in the previous cases unless imports can exceed 7 tcf per year. Thus, a simulation was conducted assuming that such a level of imports was permissible at $2.00 per Mcf. Alaskan gas was still limited to 1 tcf at $3.00 per Mcf and Mexican gas imports remained at 730 billion cubic feet at $2.00 per Mcf. Figure 13depicts the results of this simulation.

The price for synthetic, imported, and Alaskan gas is $2.41 per Mcf and the rolled-in price of gas becomes $1.87 per Mcf. Imported gas would comprise approximately 13 percent of the national need. Some interesting flows would also emerge. As shown in Figure 13, the optimal supply system would involve a displacement of synthetic fuels toward the interior of the country while imports service the East and West coasts. For instance, the Pennsylvania facility provides gas to Ohio and the West Virginia site transfers gas to Indiana. A similar type of energy transfer exists in the West. The Northern Great Plains facilities serve the Upper Midwest states while Alaska serves the Upper Great Plains. This type of system requires interregional and interindustry cooperation and coordination.

Therefore, the "technical fix" demand estimate can be met through the importation of large quantities of gas and the commissioning of numerous gasification facilities. At some sites, such as western North Dakota, multiple facilities must be sited.

Discussion

Table 6 lists the price consumers pay for gas and the number of gasification sites employed for the seven



"Ford Foundation" Demand

Figure 13

Table 6: Comparison of Simulations

	\$/Mcf	sites
1. High Inexpensive Imports plus Alaskan	1.57	0
2. High Expensive Imports plus Alaskan	1.62	0
3. High Med Inexpensive Imports plus Alaskan	1.60	0
4. High Med Expensive Imports plus Alaskan	1.67	1
5. Low Med Inexpensive Imports plus Alaskan	1.69	9
6. Low Inexpensive Imports plus Alaskan	1.73	14
7. Gaseous Fuel Independence	1.77	15

simulations conducted for the FEA demand forecast. Figure 14 graphs the price of gas with the percentage that the nation is dependent upon foreign or Alaskan gas to fulfill the gaseous fuel deficit. There is an inverse relationship between the degree of gaseous fuel dependence to the price of fuel. A national policy toward gaseous fuel independence would result in consumers paying a high price for fuel in the short run. However, the attractiveness of this policy may change if the price of imported gas escalates compared to that which can be domestically produced.

Synthetic fuel production will also result in more environmental degredation within the United States compared to that which would result if more imported gas were utilized. The amount of environmental impact felt within the United States increases proportionally with increases in the amount of synthetic gas produced. For some simulations these impacts are concentrated in a few locations which can have important ramifications on the siting of the facilities. For example, a concentration of facilities may cause ambient air standards to be violated in some locations. Thus, those supply alternatives which call for a concentration of facilities may be infeasible within the current legal constraints. For instance, in the "gaseous fuel independence" simulation, it was computed to show that eight counties in western North Dakota will be subject to 30 percent of all

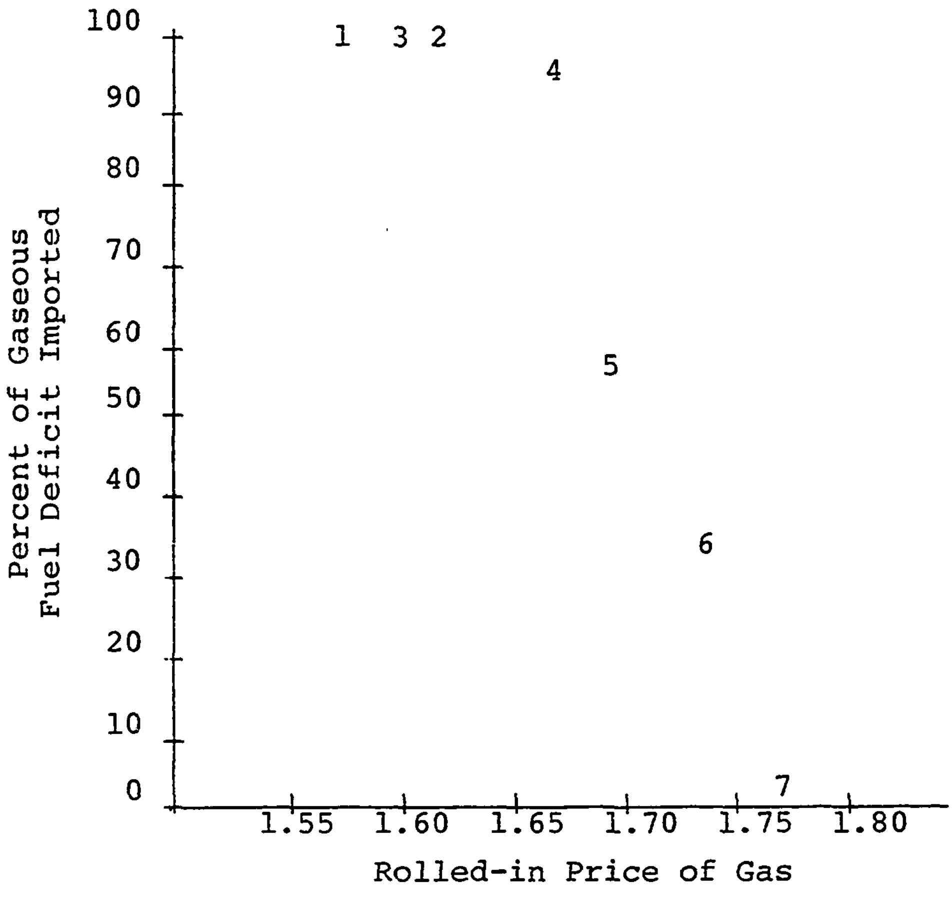

Percent of Gaseous
Fuel Deficit Imported
100
90
80
70
60
50
40
30
20
10
0
1
3
2
4
5
6
7
1.55
1.60
1.65
1.70
1.75
1.80
Rolled-in Price of Gas

Figure 14

the air emissions produced by gasification facilities in the nation. Local citizens or other interested groups may oppose such siting strategies because of the expected environmental degredation, despite the benefit of the plan to national goals. Such political and legal considerations could prevent the "gaseous fuel independence" siting policy modeled above from ever being implemented.

The ramifications which special policies may have on the preliminary simulations presented in this chapter can be viewed by adding more constraints to the model or by adjusting the model's parameters. The next chapter considers the effect of certain policies which may exclude certain sites from being utilized for coal gasification facilities. The results of these simulations can be compared to the unrestricted simulations of this chapter in terms of the price of gas to the consumers, the degree of dependence upon foreign fuel sources, the location of the facilities, and the flows between areas.

CHAPTER V

CONSTRAINTS ON THE OPTIMUM SOLUTIONS

Introduction

This chapter examines special policies that can be effectively evaluated by adding more constraints to the model. By carefully selecting constraints which portray the operation of certain factors, the costs and other consequences of certain policies can then be readily ascertained. The geographical distribution of the nodes and the patterns of flow are compared to select simulations modeled in the previous chapter. These are defined before adding any constraining conditions. The policies that exclude certain sites may hamper the system's ability to satisfy demand, may interrup service within the system, or may result in changes to the attractiveness of certain facility sites.

Many different situations can occur to eliminate certain sites from consideration for coal gasification facilities. However, most of these are determined on an individual basis and can not be successfully evaluated *a priori* through the elimination of certain sites. For example, the Endangered Species Act of 1973(P.L. 93-205; 87 Stat. 884) provides the means to exclude as possible locations for new energy facilities the critical habitat of endangered fish, wildlife, and plants. Although the location of the critical habitat of several known endangered species have been identified, it is not fruitful to use this information as a basis for excluding potential sites since many new species will probably be added to the endangered list and the environmental impact statements(EIS) required for new energy facilities can identify new endangered species not previously encountered (Bureau of Sport Fisheries and Wildlife, 1973). The denial of necessary permits by state and federal agencies,which can not be predicted beforehand, can also effectively eliminate proposed sites from consideration.

Important policy options that can eliminate certain sites from consideration that are included in this analysis are: (1) Class I clean air "buffer zones"; (2) avoidance of water availability problem areas; (3) avoidance of possible United Mine Worker strike interruptions; and (4) the exclusion of large scale western energy resource development. These are evaluated in turn and compared to the earlier simulations in which no such restrictions existed.

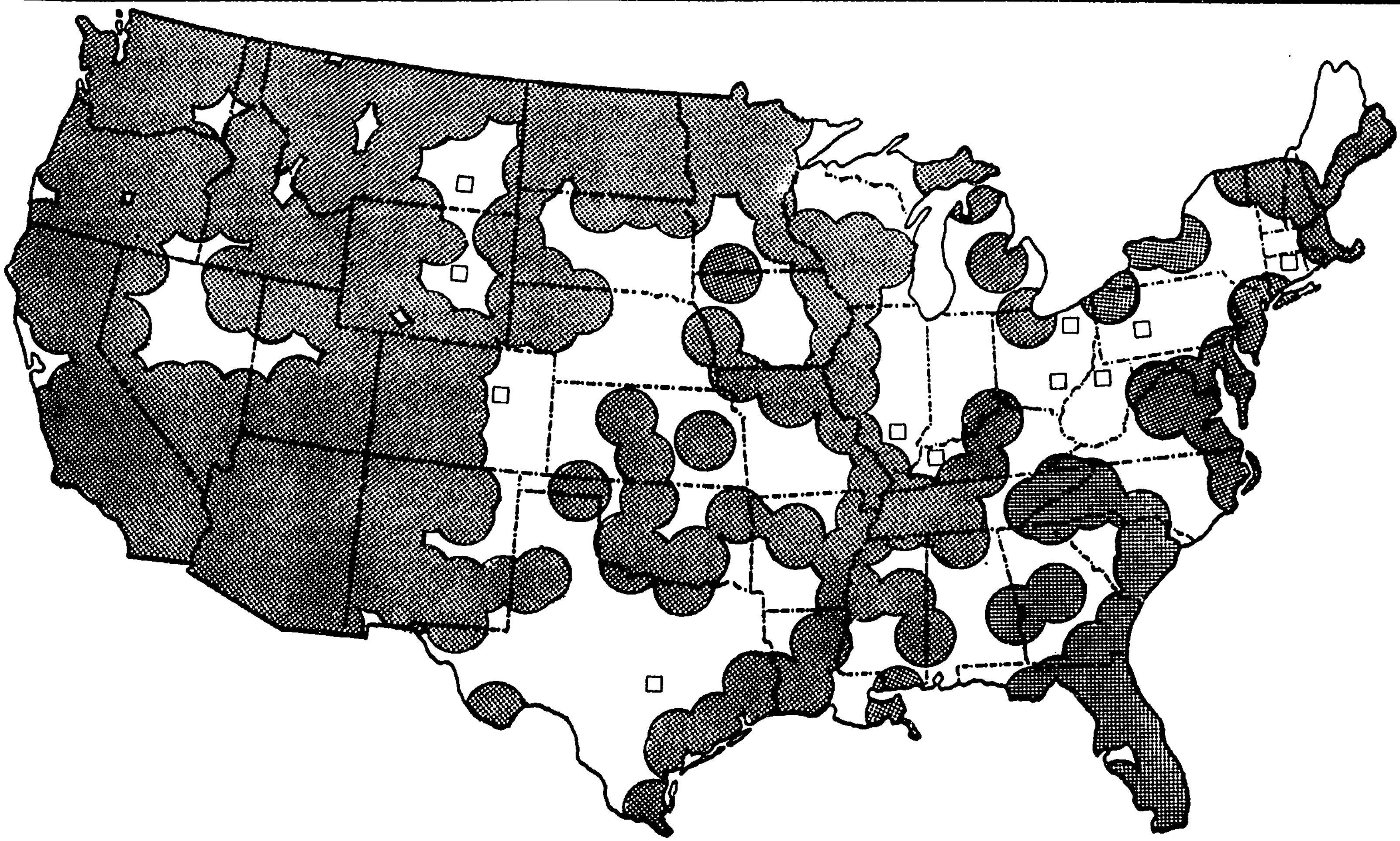
Class I Clean Air "Buffer Zones"

Several aspects of the Clean Air Act Amendments of 1977, particularly Section 127, might affect energy facility siting strategies and may exclude certain sites from consideration. A major concern for energy developers is the designation of

Class I air quality regions and the possible imposition of "buffer zones" to prevent the significant deterioration of Class I air quality. International parks of any size and national parks and national wilderness areas in excess of 5,000 acres may be designated Class I areas(Committee on Environment and Public Works, Subcommittee on Environmental Pollution, 1977:7). It appears that the West, for example, will have many Class I areas because of the large number of national parks and wilderness areas located in the region. Some of the gasification facilities announced for the West are expected to have noticeable impacts on Class I areas. The Southwest Director of the National Park Service, for instance, has expressed concern that pollutants emitted from the WESCO gasification project may corrode Anasazi ruins at nearby Chaco Canyon(U.S. Department of the Interior, Bureau of Reclamation, 1976:10-3). Although the delineation of rigid "buffer zones" are not defined within the Clean Air Act Amendments, the implementation of the Act may result in the development of implicit buffer zones for certain types of facilities(Committee on Environmental and Public Works, Subcommittee on Environmental Pollution, 1977:7). Buffer zones may be established around Class I areas since the pollutants from new facilities must be diluted by atmoshperic mixing to meet the low concentrations allowed in nearby Class I areas (White, <u>et al</u>., 1977:36). Permission could be denied for a site that air modelling shows is expected to adversely affect nearby Class I areas. The issuance of multiple siting denials in proximity to a particular Class I area would result in an *ex post facto* "buffer zone".

Numerous maps have been published delineating possible "buffer zones" around Class I areas. These depend largely on the type of facility being constructed. For instance, a coal burning electric power plant is expected to have "buffer zones" up to five times larger than coal gasification facilities(White, *et al.*, 1977:36). Because it is not possible to model the atmospheric mixing for all the sites chosen in this study, an arbitrary "buffer zone" is drawn around each announced site. A map with fifty mile "buffer zones" around Class I areas was published jointly by FEA and EPA. This size of "buffer zone", although greatly exaggerated for coal gasification facilities, portrays the effect of a strict clean air policy on siting strategies. Figure 15 illustrates the exclusionary areas if energy facilities are not permitted to locate within fifty miles of Class I areas. This map is employed to eliminate certain gasification sites from the spatial allocation model.

The imposition of fifty mile radius "buffer zones" eliminates seven of the announced nineteen gasification sites from consideration. Without the synthetic fuel from these seven sites it is impossible to achieve the FEA based "gaseous fuel independence" policy goal. Thus, the policy of developing fifty mile "buffer zones" around Class I areas eliminates



LAND AREAS POSSIBLY PRECLUDED FROM SITING NEW ENERGY FACILITIES UNDER CLEAN AIR ACT GUIDELINES

Source: U.S. Environmental Protection Agency, Federal Energy Administration

Figure 15

any possibility of achieving gaseous fuel independence according to the parameters utilized in this study.

If the FEA-based low medium inexpensive imports plus Alaskan gas simulation(simulation 5) is employed, gaseous fuel demand can be satisfied. The flows of synthetic, imported, and Alaskan gas for this case are shown in Figure 16. Surprisingly, however, the combined price of gas from these sources is $1.69 per Mcf, only one-half cent per Mcf above the similar case in the previous chapter where no "buffer zones" were added. This figure computes to approximately 117 million dollars annually for achieving fifty mile radius Class I buffer zones.

If the 1985 Ford Foundation forecast is utilized, the imposition of fifty-mile Class I "buffer zones" makes it impossible to satisfy demand even when seven trillion cubic feet of LNG is imported. Therefore, if gaseous fuel demand exceeds 30 tcf by 1985, the exclusion of many gasification sites could greatly increase the nation's dependence on foreign fuel sources. The effect of these "buffer zones" is to increase the price of gas to the consumer somewhat while making it more difficult to satisfy national gas demand. Thus, a clear tradeoff exists between the national goal of decreased energy dependence and increased environmental protection.

Avoidance of Water Availability Problem Areas

Another constraint which may exclude certain sites from

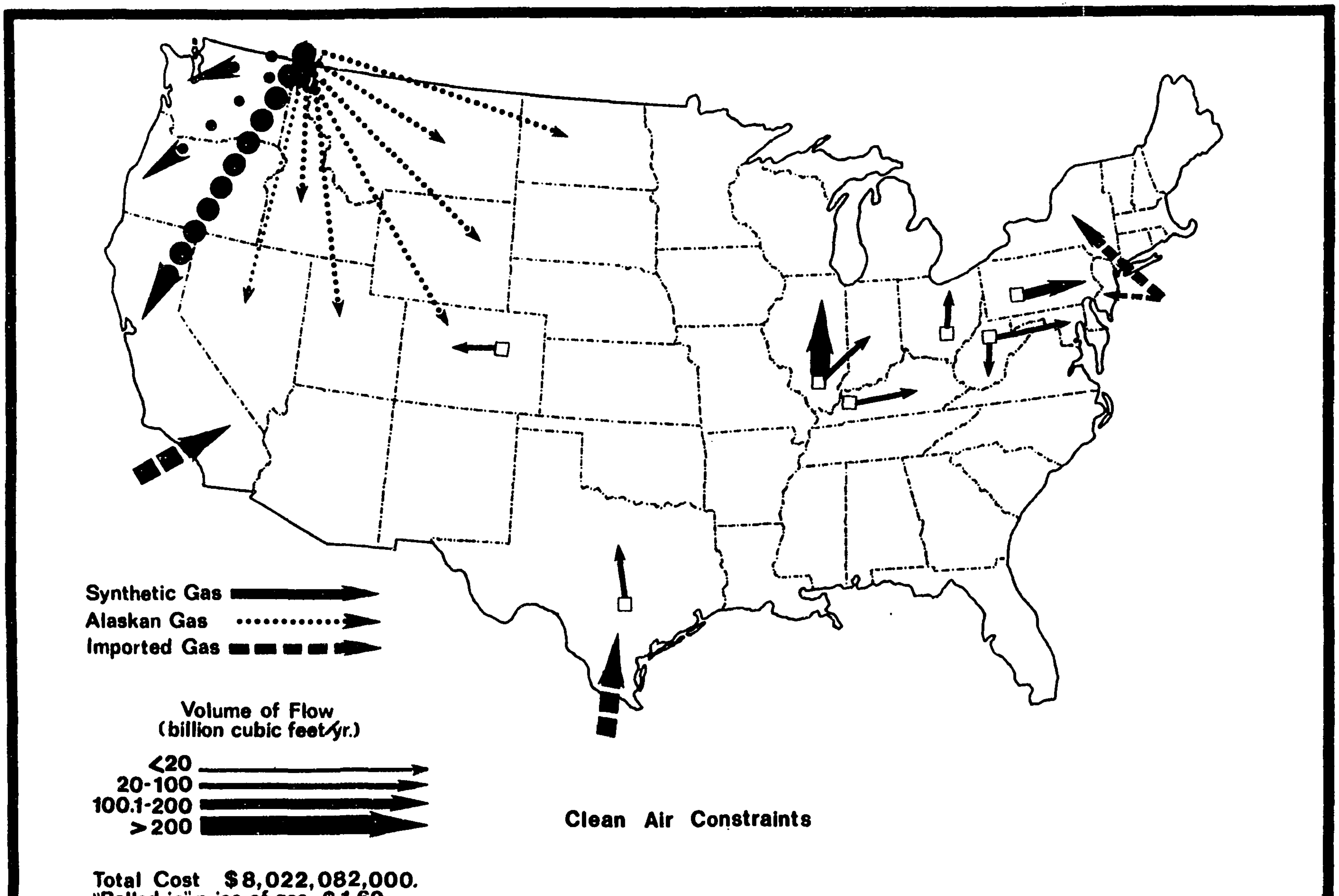
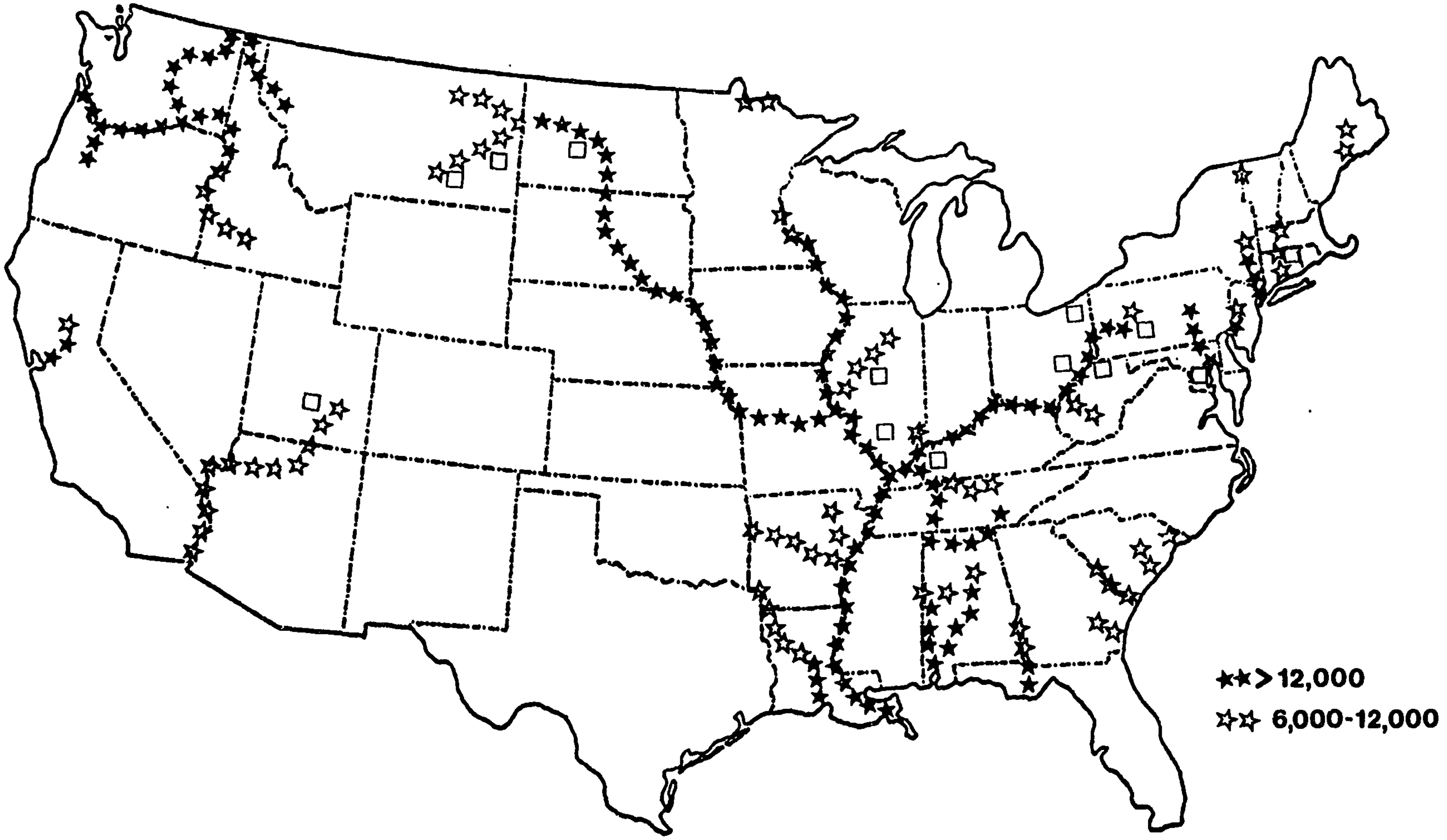

Synthetic Gas
Alaskan Gas
Imported Gas
Volume of Flow
(billion cubic feet/yr.)
<20
20-100
100.1-200
>200
Clean Air Constraints
Total Cost $8,022,082,000.
"Rolled-in" price of gas $1.69

Figure 16

consideration is the availability of water. Compared to other energy conversion facilities, Lurgi gasification plants are not excessively water intensive. In fact, Lurgi gasification facilities use half as much water as synthane gasification facilities, the major alternative to Lurgi(Water Purification Associates, 1977:7). However, the problems with securing water use permits have been identified as a major issue in the development of coal gasification(Messing, 1977:187). Although much attention has addressed water availability problems in the West, recent studies suggest that water may be sufficiently short in the East as well, constraining energy development in that region(U.S. Department of the Interior, 1975; Dobson, 1977).

Most energy developers prefer to site coal conversion facilities within five miles of available water supplies(Kuiken, et al., 1977). Figure 17 shows rivers in the United States which have large flow rates. To model the affect of a policy that avoids water availability problem areas, those sites not adjacent to these rivers or other large surface sources of water(e.g., Lake Erie) are excluded from consideration. As shown in figure 17, only thirteen gasification sites can be activated.

Assuming that those gasification sites not shown on the map are denied siting permission, "gaseous fuel independence" can not be achieved for either demand forecast. However, by adding Alaskan supplies, the FEA demand estimate can be met

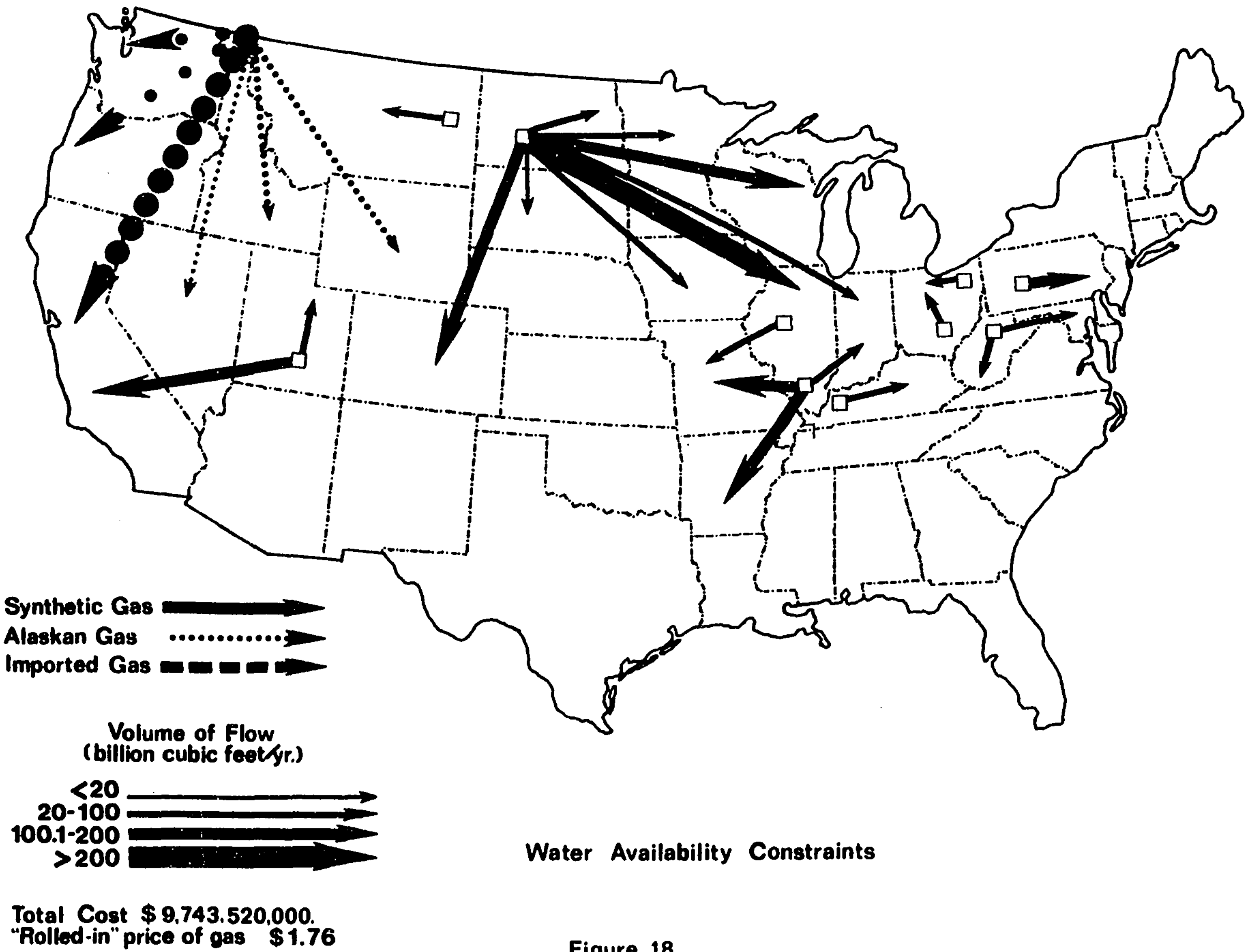


ANNUAL RIVER FLOW RATES (20-yr. low flow)
(cubic feet per second)

Figure 17

without importing any gas. Figure 18 shows the system necessary to achieve this goal. The combined cost of synthetic and Alaskan gas is approximately $3.18 per Mcf and the rolled-in cost of all gas is $1.76 per Mcf. This is 16 cents per Mcf more expensive than if water availability is no problem and imports can be used. However, this case results in only a slight rise in the price per Mcf from a case in which no imports were used. The cost to the system of excluding certain sites because of water availability problems is approximately $34 million per year. This $34 million comprises the additional transport costs incurred by utilizing gasification sites other than those used in the optimal solution. Policymakers can evaluate each of the sites which have water availability problems to determine if a marginal investment in increasing water supplies yields greater transport savings for the entire system. Such an investment can be for interbasin water transfer, subsurface water exploitation, or the implementation of water saving technologies.

The Northwestern New Mexico gasification site, for example, was eliminated because of water availability problems. However, if no constraints other than no imports are imposed, the optimal solution has the Northwest New Mexico site producing 440 billion cubic feet of synthetic gas annually, the largest producing site in the nation. Considering this fact, another water availability simulation was conducted in which the New Mexico site was included. By utilizing this one



Water Availability Constraints

Figure 18

additional site, $16.4 million in transportation costs can be saved annually to the entire system. Therefore, it makes sense to evaluate options of increasing the water supply at this site since its location with respect to the markets and existing pipelines is so advantageous.

As shown in this example, the model can be helpful in testing policy alternatives that focus upon investing in particular sites to benefit the system as a whole. Such measures can be pursued in other cases in which a facility site is excluded for one reason or another.

Avoidance of Possible United Mine Worker Strike Interruptions

Natural gas is continuously supplied from the source area to the markets. As such, the supply of natural gas is impervious to supply interruptions that may arise from labor strikes, poor weather, or traffic congestion. However, synthetic gas is not immune to such service interruptions until after the gas is into the pipeline. Problems at the gasification facilities, coal mines, rail links, or conveyors feeding the plants could interrupt gaseous fuel movement to the consumers. Therefore, although synthetic gas provides consumers with many of the amenities of natural gas, it is not necessarily a continuously flowing fuel.

The vulnerability of flows to service interruptions is spatially dependent in many cases. For instance, gasification facilities dependent upon coal produced from mines controlled by unions may be candidates for supply interruptions. A

United Mine Workers(UMW)[1] strike, for example, could interrupt coal supplies to some gasification facilities. Policymakers may decide that continuous flow is a desirable characteristic of a synthetic gas supply system and may want to develop a system as independent of these UMW controlled strikes as possible. The following simulations evaluate the effects of pursuing such a policy and shows that for the lower demand estimate national gaseous fuel demand could still be met by utilizing non-union controlled coal. Of course, simulations could be generated for other policies that would help to mitigate the possibility of subjecting the synthetic fuel supply system to possible supply interruptions.

It is possible that a unified UMW strike could occur. Although recent years have been marked by local "wildcat" strikes(over 5000 have occurred since 1974), the new UMW President has called for unity(Coal Age, 1977:13). While the union is aiming to organize the West, the majority of UMW controlled mines are in the eastern part of the country (Coal Age, 1977a:15). It is possible that a unified UMW strike, then, could stop coal supplies to eastern gasification sites. These simulations consider the affects of avoiding such sites in locating new facilities.

For either the FEA or Ford Foundation demand estimate, a

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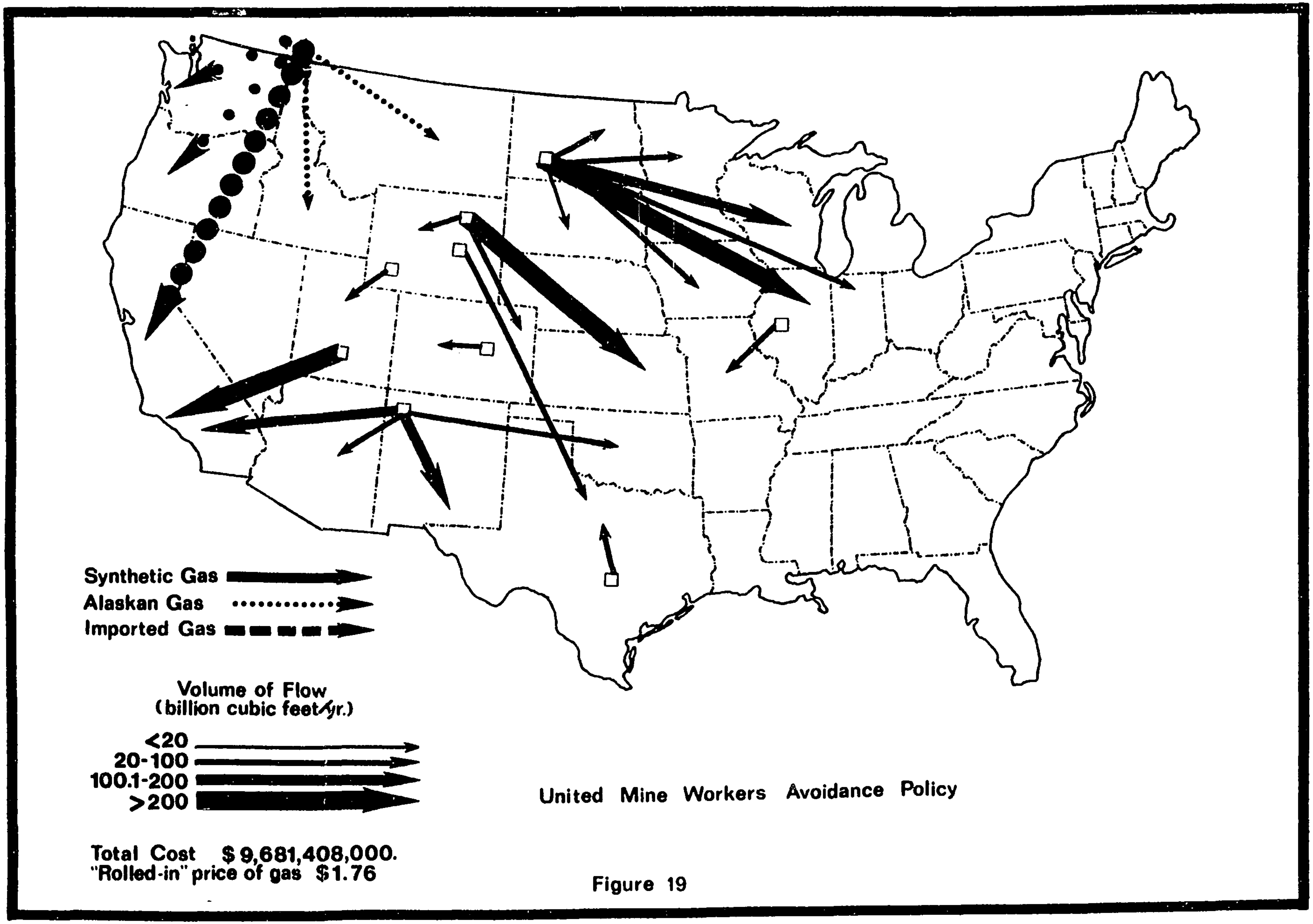
[1]The UMW is probably the most significant labor force in the entire energy system, as demonstrated by its ability to gain passage of the Coal Mine Health and Safety Act of 1969 (see, Kash, et al., 1976:46).

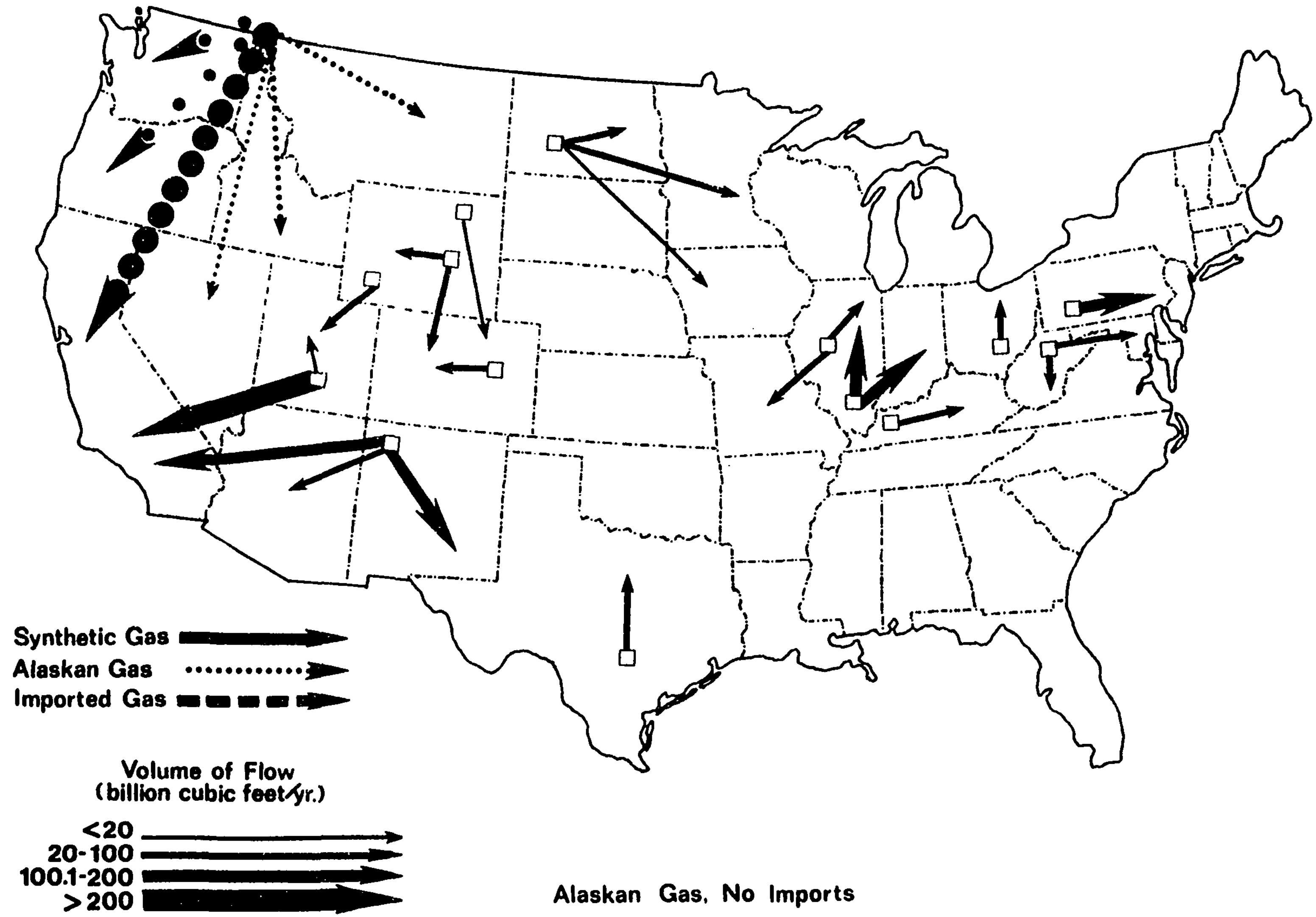
unified UMW strike, however, would not have a great effect on those simulations in which large amounts of imports or Alaskan gas are added. For instance, if the low-medium inexpensive imports plus Alaskan case(simulation 5) is considered, the annual added transfer costs of not using UMW-controlled sites would be $59 million. However, if UMW-controlled sites were operating and a strike occurred, the cost of the interruption would be much more than $59 million as an instant acquisition of new gaseous supplies would be impossible(having large stockpiles of coal on hand in event of a strike may lessen the impact of a supply interruption). Even if it were technically possible to obtain additional reserves, legal barriers might prevent a rapid alteration in the synthetic gas supply system.

Figure 19 shows the optimal synthetic and Alaskan fuel supply system for FEA's 1985 demand estimate under a UMW avoidance policy if no imports are used. This is compared to Figure 20 which shows the optimal system for the same conditions without avoiding UMW-controlled sites. When strike-prone sites are avoided, the additional costs of the system is approximately $92 million per year. Also, there must be large scale flows of gas from the West to the Middle West. In addition, the natural gas exporting states of Kansas, Oklahoma, and Texas must import synthetic gas so that they can export natural gas supplies eastward(the flows of natural gas are not shown on the map).



United Mine Workers Avoidance Policy

Figure 19



Total Cost $9,589,402,000.
"Rolled-in" price of gas $1.76

Figure 20

Avoiding those sites which may be prone to UMW initiated strikes makes it impossible to satisfy 1985 gaseous fuel demand even if over 7 tcf of imports are added. The amount of national security and transport savings incurred by using UMW-controlled sites makes it important for policies to be pursued that prevent such massive shutdowns.

Exclusion of Large Scale Western Energy Resource Development

A major source of concern is that the West may become the "boiler of the nation". A rift is developing between some western energy producing states and energy consuming states in the East. For instance, officials in Montana have announced that they do not intend to be subjugated to outside "exploitation" and have passed tough energy facility siting laws to prevent this.[1] In particular, the state of Montana requires an application fee of approximately $2 million for a $1 billion coal gasification project(Montana Major Facility Siting Act of 1975).

On a larger scale, a war of words exists between such regional organizations as the Western Governors' Conference (WGC) and the Coalition of Northeastern Governors(CONEG). The WGC argues that the West should not be forced to bear

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[1]For example, Micheal Billings, the budget director for the state of Montana, has expressed empathy for Arab actions. "To my way of thinking," he said, "the Arabs are doing what they should have done long ago when they were exploited by the oil companies." He contends that similar exploitation has occurred in Montana. "We've made some people in other states and countries extraordinarily wealthy from our copper but there's nothing left for us. We're not going to let that happen again" (Richards, 1977).

the environmental and socioeconomic costs of large scale energy development to subsidize the energy needs of the industrial states. Further, they argue that the Northeast should develop its Outer Continental Shelf(OCS) resources. CONEG governors affirm that they are already laden with negative impacts from present industries and that their federal taxes have subsidized the development of the West (Pierce, 1976:1699). A regionally unified drive by the western states to curtail energy development in the region would severely hamper national goals of increasing domestic energy development.

Seventy percent of the synthetic gas potential from announced facilities is located in the Rocky Mountain-Northern Great Plains states. The Northeast and Middle West states have less than thirty percent of the announced synthetic gas potential. Clearly, any national drive to increase synthetic gas supplies in the short term must utilize western gasification sites.

Without the synthetic gas potential from the West, it is not possible to achieve "gaseous fuel independence", even with the addition of Alaskan gas. Therefore, any regional policy which prevents the siting of gasification facilities in the West binds the nation to a policy of depending upon gaseous fuel imports. However, it is possible to meet FEA's 1985 demand estimate for the low-medium inexpensive imports plus Alaskan case(simulation 5). This system incurs an additional transport cost of $4.4 million per year by excluding western sites. Although the additional transport cost incurred by not developing the West is quite small, a policy which excludes these sites makes it impossible to satisfy gaseous fuel demand when the Ford Foundation's demand estimates are employed. Moreover, it restricts the flexibility in the East because seven of the ten potential sites must be utilized. A closure of one of the major facility sites, such as by a "wildcat" strike closing the West Virginia facilities, could severely strain the system and lead to immediate gas curtailments.

Not all western states are cautious about energy development plans. Utah, for example, is a supporter of increased energy development. State policymakers feel that their wishes are being undermined by federal policy that excludes certain sites from energy development and impose standards on the use of others. The state of Utah is trying to eliminate Class I buffer zones so that more sites can be opened for energy development.[1] Although other western states may be moving slowly on energy development, it is possible that Utah could become the "boiler of the West."[2]

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[1]Al Richers, Director of Utah's Air Conservation Committee, explains that "we did away with the idea of arbitrary buffer zones because it takes too much land away from development"(Gill, 1976).

[2]It is clear that other western states are not totally opposed to energy development, but most want more attention devoted to socio-economic and environmental concerns(Federation of Rocky Mountain States, 1975).

A simulation was conducted in which the only gasification site utilized in the Rocky Mountain-Northern Great Plains states is the site in Southern Utah. However, the optimal solution did not utilize this site. This is because of all the possible western facility sites, the Southern Utah location is not among the most economical. A simulation in the next chapter considers the effects of a direct policy to utilize facility sites in Utah.

Conclusion

As shown by these examples, numerous alternative strategies can be followed which avoid certain sites. Avoiding some sites increases the dependence upon foreign or Alaskan gas, necessitates the interregional flow of gas, and results in rises in the price of gas. Therefore, policies such as those illustrated in this chapter make site-avoidance policies economically inefficient and run counter to the goal of decreased foreign fuel dependence. On the other hand, to pursue the policies examined in this chapter would not be excessively expensive compared to the overall national fuel bill. Table 7, for example, compares the additional cost and number of sites utilized for site-avoidance policies as compared to a particular base case. An annual increase of $117 million for pursuing a policy of not siting gasification facilities within fifty miles of Class I areas may be a bargin compared to the overall fuel bill. Interested policymakers could compare the costs of these site-avoidance policies to the benefits derived from them.

Table 7: Comparison of Site-Avoidance Policies*

Simulation	Increase in Total Cost (in millions/year)	Number of Sites
Base Case	0	9
Clean Air "Buffer Zones"	117.0	7
Water Availability	2.5	7
UMW-area avoidance	59.0	9
Non-Western Orientation	4.9	7

* All simulations are compared for the "low-medium inexpensive imports plus Alaskan simulation discussed in the previous chapter.

CHAPTER VI

MODELLING EXISTING CONDITIONS

Introduction

Experiments are now reported which model conditions and policies that would change the attractiveness of different sites. These results are accomplished by adjusting the values of the parameters in the equations. Incorporated into the results are existing conditions that make the solutions more representative of reality. A comparison between a "market-oriented" siting strategy to the expected minemouth pattern is evaluated. To accomplish this, it is necessary to add new sites for coal gasification facilities. The simultaneous imposition of several constraints and policies of the previous chapter to the adjustments of the parameters and the addition of new sites allows greater breadth in the applicability of the results.

The attractiveness of sites can be influenced in many ways. Previous simulations have shown that minemouth facilities are more attractive economically than those requiring long distance coal hauls. Other cases have not been considered. The residuals of a standard size Lurgi gasification facility, for example, will generally have different impacts on the environment depending upon the particular characteristics of the site(White, et al., 1977). The inputs needed for the facility also differ according to site. For instance, facilities using coal with high water content need not employ as much water as a facility using coal with a lower water content. Laws, regulations, and taxes also alter the attractiveness of different sites. The stringent siting law in Montana with its high application fee lessens the attractiveness of locating there. On the other hand, the prodevelopment posture of Utah may give that state an intangible advantage over other more competitive sites elsewhere. In sum, a high degree of variation can be distinguished among the announced gasification sites.

Because of the large number of permutations possible, most simulations in this chaper use simulation 6 in chaper four that assumes a low amount of inexpensive imports as a baseline situation(LNG imports $\leq .4$ tcf/year @1.30 per Mcf; Alaskan gas ≤ 1 tcf /year @3.00 per Mcf). This simulation represents a rather realistic comprise between the "gaseous fuel independence" case and one relying upon large scale gas imports.

Simulations reported in this chapter show the effects of policies which change the attractiveness of different sites. These include:(1) the effects of the new Strip Mine

Act(P.L. 95-87; 91 Stat. 445, August 3, 1977); and (2) the impacts of state severance taxes on coal and synthetic gas. Then, a simulation is conducted in which a "market oriented" location strategy is followed(which necessitates that new facility sites be added to the system). Finally, simulations that combine some of the constraints analyzed in Chapter Five are reported. These simulations provide the basis for an evaluation of the synthetic fuel supply system as it may exist if present trends and policies continue.

Implementation of the Strip Mine Law

On August 3, 1977, President Carter signed into law the "Surface Mining Control and Reclamation Act of 1977". This Act presents broad measures to reduce the negative impacts of surface mining in the United States. Because of the large-scale coal strip mining activities expected to occur along with many new coal gasification projects, this Act will influence the price of gas. Besides having clauses which establish new strip mining procedures, the Act requires that coal mining operators pay fees before engaging in mining operations. Surface coal mine operators must pay a fee of 35 cents per ton of coal produced whereas underground mining operations must pay 15 cents per ton produced (P.L. 95-77, Sec. 402(a)).

Conceivably, this act could lessen the attractiveness of surface coal mine sites while increasing the attractiveness of underground mine sites by increasing the cost of surface-mined coal with respect to coal that is produced from underground facilities. However, a simulation conducted with this change in the parameters did not result in a change in siting patterns. The result of the simulation was to increase the cost of the optimal solution about $28 million above the unconstrained case. The optimal solution with the affects of the new Act did not include any changes in the distribution of the gasification sites utilized or in the flows among the links.

Severance Taxes

A major source of rivalry between western energy producing states and major consuming states has been the levying of severance taxes on energy resources by the energy rich states. Much rhetoric has been exchanged by representatives of the two areas.[1] However, the claims that high severance taxes will necessitate a great increase in the cost of gaseous fuel and energy dependence have not been substantiated by this model.

For a particular utility that uses coal gasification facilities in states with high severance taxes as a large portion of the total gas supplies, the cost to the consumers could be considerable. For instance, a utility using a

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[1]Individuals from energy consuming states have dubbed energy rich westerners as "Blue-eyed Arabs" while some westerners maintain that the plans of out-of-state utilities to develop western energy resources constitutes modern day colonialism(see, Richards, 1977).

Montana site would pay approximately $28 million per year in severance taxes. This would increase the price of gas from that facility approximately 34 cents per Mcf.

On the other hand, if a national synthetic fuel supply system were incorporated in which developers avoided states that levy high taxes, the results would not be so costly to each developing firm. By employing sites which incur greater transport costs, an economically efficient solution can be found which still satisfies national demand. A simulation was conducted in which the severance tax for each state was included into the system.[1] The optimum solution did not include any facilities in the high tax states of Montana, North Dakota, or Wyoming. The additional cost of the system compared to the unconstrained case was only $10.5 million annually. Such an expense is quite small compared to the effects of other conditions modelled previously.

Market Oriented Locations

One possible way to relieve some conflict in locating gasification facilities is to site the facilities adjacent to metropolitan demand areas. This "strip and ship" pattern of development will reduce many of the undesirable impacts in the resource area(which may not need increased gas supplies) while increasing the impacts in the demand center which needs the fuel. It has been shown that many

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[1]Information on these taxes was taken from Stinson(1976) and Bronder(1976).

of the impacts of coal conversion facilities can be attenuated by siting near major consuming cities(Metzger and Stenehjem, 1977). For instance, a large class of impacts occur in isolated resource-rich regions because of the rapid influx of workers needed to construct and service the new conversion facilities. Coal gasification facilities are particularly labor intensive during the construction phase and require peak construction employment of 4,600 workers(Bechtel, 1975: 6-31). The remote areas in which most of the announced facilities are to be located do not have such a specialized and large work force readily available. The inmigration of these workers spurs many impacts to isolated areas, such as congestion, housing shortages, increased crime, automobile pollution, and rising land values. If a facility were to be sited near its primary load center, the city could supply most of the necessary workers without having the problems associated with large scale population settlements (Metzger and Stenehjem, 1977:8). However, such a siting strategy would increase air pollution in an already polluted area creating problems in attaining local ambient air standards and posing a health hazard.[1]

Several possibilities of supplying synthetic gas through a market-oriented strategy are considered. Since only four of the announced facility sites can be truly considered to be market-oriented(Conneticut, Baltimore,

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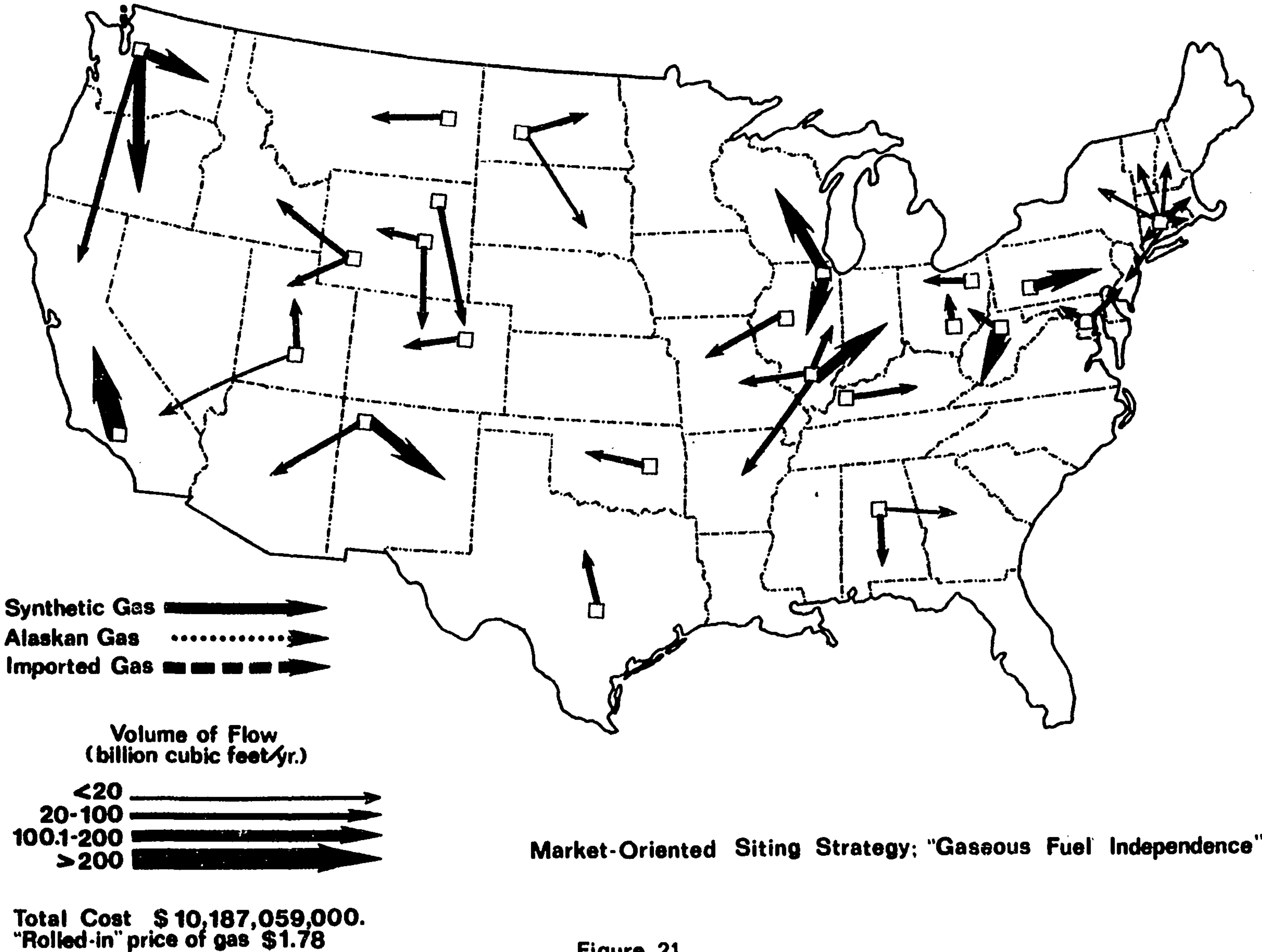
[1]Air pollution problems in isolated areas which cause a violation of non-significant deterioration standards is more of an aesthetical problem than a health problem.

Northeast Ohio, and Western Pennsylvania) other possible locations for sites were added. These new locations are Birmingham, Alabama; Eastern Oklahoma; Wichita, Kansas; Chicago, Illinois; Los Angeles, California; and Seattle, Washington. Although the Oklahoma and Wichita sites are not adjacent to major markets they are added because of unpublished reports of siting gasification facilities at these locations. A simulation was conducted in which the Connecticut, Maryland, Pennsylvania, Northeast Ohio, Chicago, Los Angeles, and Seattle sites were utilized. The preliminary simulation considered the possibility of attaining "gaseous fuel independence" without relying upon Alaskan sources for FEA's 1985 forecast.

As shown in Figure 21 , such a configuration does satisfy gaseous fuel demand. The optimal solution includes 23 gasification facility sites and costs $10.2 billion. This results in a cost of $3.32 per Mcf of synthetic gas. However, the solution still requires that eight of the sites in the Rocky Mountain-Northern Great Plains states be utilized although only one large flow of synthetic gas from this region occurs(from Kaiparowits to California). Therefore, although the "gaseous fuel independence" scenario is attained through the utilization of market oriented facilities, it is still necessary to employ gasification sites in the areas adjacent to the resources.



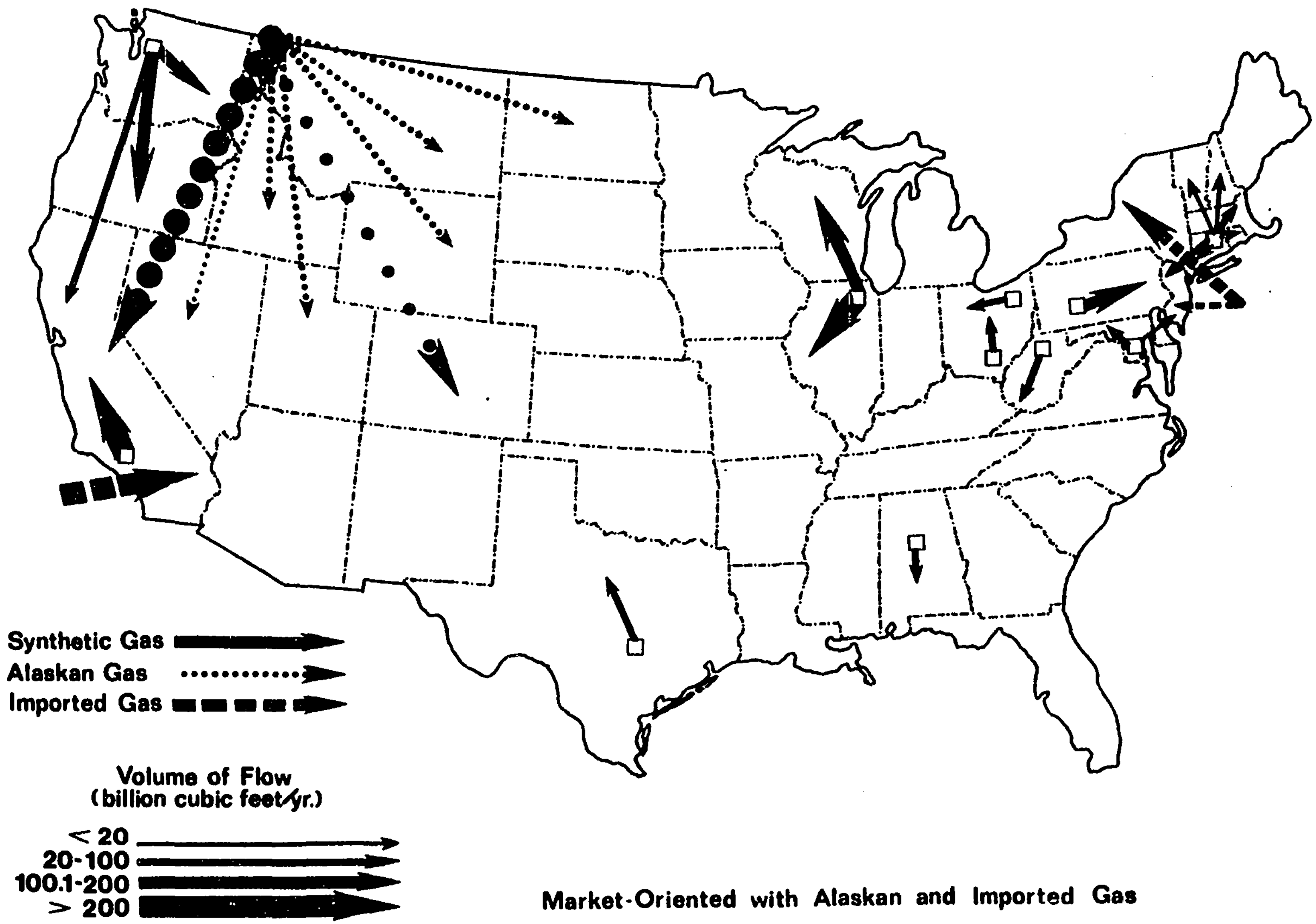
Market-Oriented Siting Strategy; "Gaseous Fuel Independence"

Figure 21

If the assumption is that only low inexpensive imports plus Alaskan gas is added to the system(simulation 6), the optimal solution requires the use of only three other gasification facilities(West Virginia, Southern Ohio, and Texas). This pattern is shown in Figure 22. The additional cost of pursuing a market-oriented location strategy over the unconstrained conditions in Chapter 4(simulation 6) is \$420 million annually. This increases the cost of gas to the consumers by approximately 14 cents per Mcf. However, such price increases do not fall equally to all regions of the country. Washington state, for instance, would pay approximately \$3.86 per Mcf for synthetic gas produced at the Seattle facility. This SNG would supply the Seattle market with all of its gaseous fuel needs. By having a market location, Seattle would pay extraordinarily higher prices for gas while being subjected to the undesirable impacts of the energy facility. Thus, a conscious effort to have market-oriented locations would depend upon some government intervention to distribute the costs of the gas among other consumers.

Market Oriented with Additional Costs

A more realistic view of the costs of such a market-oriented siting strategy is derived by incorporating the costs of the reclamation law and severance taxes discussed previously into the market-oriented simulation. The resulting



Total Cost $9,302,477,000.
"Rolled-in" price of gas $1.76

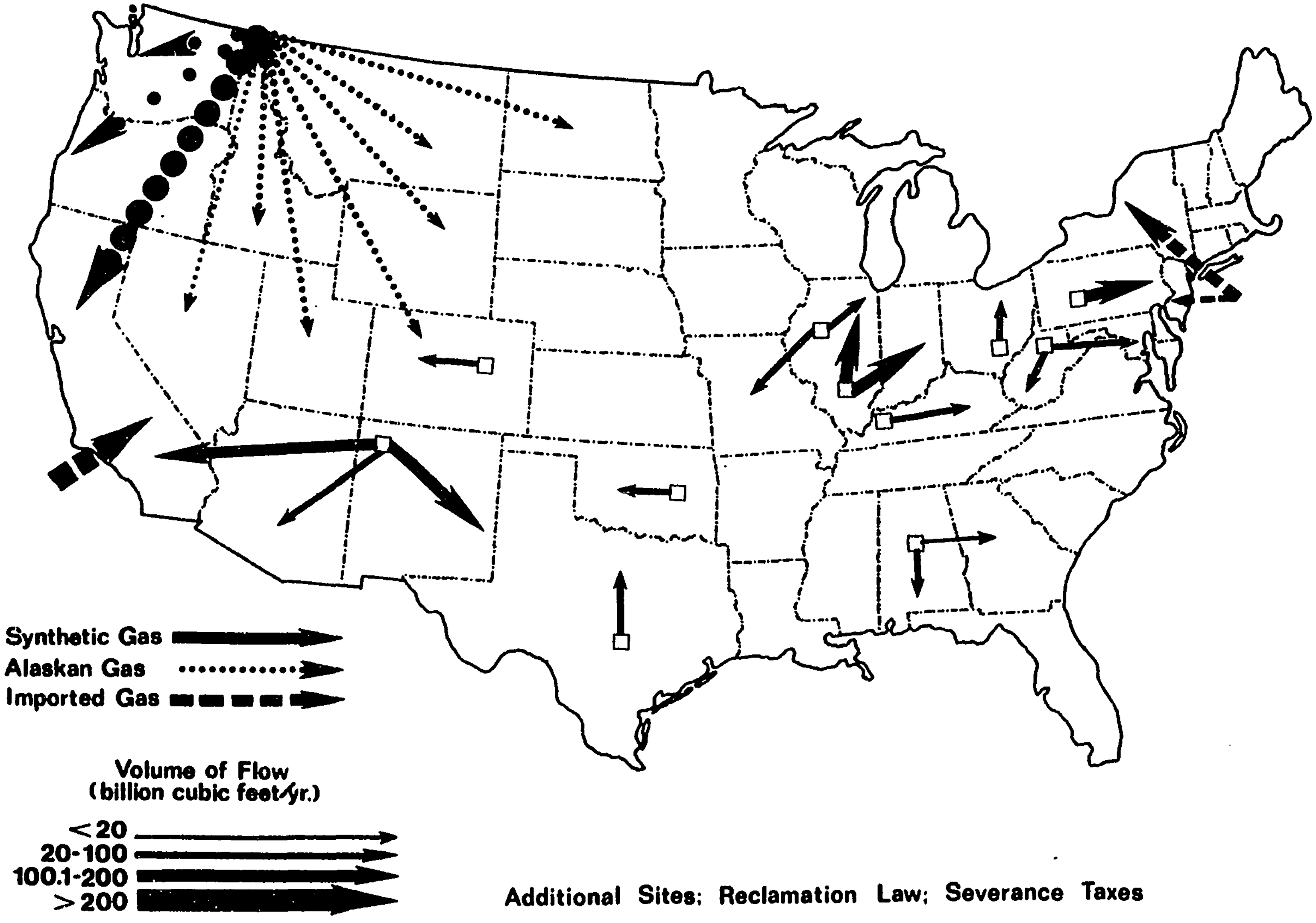
Market-Oriented with Alaskan and Imported Gas

Figure 22

pattern is somewhat different from the previous case as the West Virginia facility is avoided because of that state's coal severance taxes. Adjustments in the system are made by the addition of the Denver facility, located in a state with low severance taxes. The cost of this more realistic simulation is $586.6 million per year greater than the preliminary case in Chapter 4. It is also $163.3 million greater than the case in which no severance taxes or reclamation law was in effect. The "rolled-in" national price of gas rises from $1.73 per Mcf in the unconstrained case in Chapter 4 to $1.76 per Mcf. The financial impacts of the combination of a market-oriented siting strategy with both the reclamation law and severance taxes are not serious if the costs can be computed nationally. If rolling-in of costs does not occur, the expense of such a siting strategy for a particular utility could be staggering. Such information could provide the basis for a more comprehensive cost/benefit analysis to determine whether the benefits of these policies outweigh this annual increase in costs to the consumer.

Additional Sites, Reclamation Law, Severance Taxes

Figure 23 illustrates the optimal flows of a system based upon simulation 6 in Chapter 4 which has additional sites, considers the effects of the reclamation law, and has state severance taxes incorporated. Gaseous fuel demand can



Total Cost $ 8,940,717,000.
"Rolled-in" price of gas $1.73

Additional Sites; Reclamation Law; Severance Taxes

Figure 23

be achieved with the "rolled-in" price of gas at approximately $1.73 per Mcf, only $59 million greater than the solution found in Chapter 4.

The results of this simulation are interesting in several respects. First, the results show that large scale development of western energy resources is not needed for deploying coal gasification facilities to relieve domestic gaseous fuel shortages. Only two western facility sites are employed, Denver and Northwestern New Mexico. The Denver facility serves a local market while the New Mexico facility sends 44 percent of its output to California. No large scale movements of western energy to the Middle Western, South Central, or Eastern states occur. Also, no facility sites in the coal-rich Northern Great Plains states are utilized. These results do not indicate that large scale development of western energy resources is necessary to satisfy future gaseous fuel demand.

Second, Alaskan gas is sufficient to satisfy gaseous fuel demand for the Northwestern states. This gas also relieves the pressure of the huge California market(California would receive 350 billion cubic feet of Alaskan gas annually). The addition of large quantities of Alaskan gas into this market permits larger quantities of the natural gas production of Texas, Kansas, and Oklahoma to serve the Middle Western states. These results are beneficial from a national viewpoint as pipelines are already in place to ship gas in this direction.

Third, the facility sites of the Middle West and Appalachian states are heavily utilized(92 percent of capacity in this region is activated). This is so even though West Virginia and Kentucky have coal severance taxes(albiet low taxes). However, the Chicago site is not employed because it incurs high rail transport costs. Therefore, a large portion of the gaseous fuel deficit in the Middle West can be alleviated by activating most of the announced gasification facilities in the region.

Fourth, the states with high severance taxes are avoided as either sites for coal gasification facilities or source areas for coal used in these facilities(Montana, Wyoming, and North Dakota). The total cost of the solution is less expensive because those states with high taxes are avoided as potential sites.

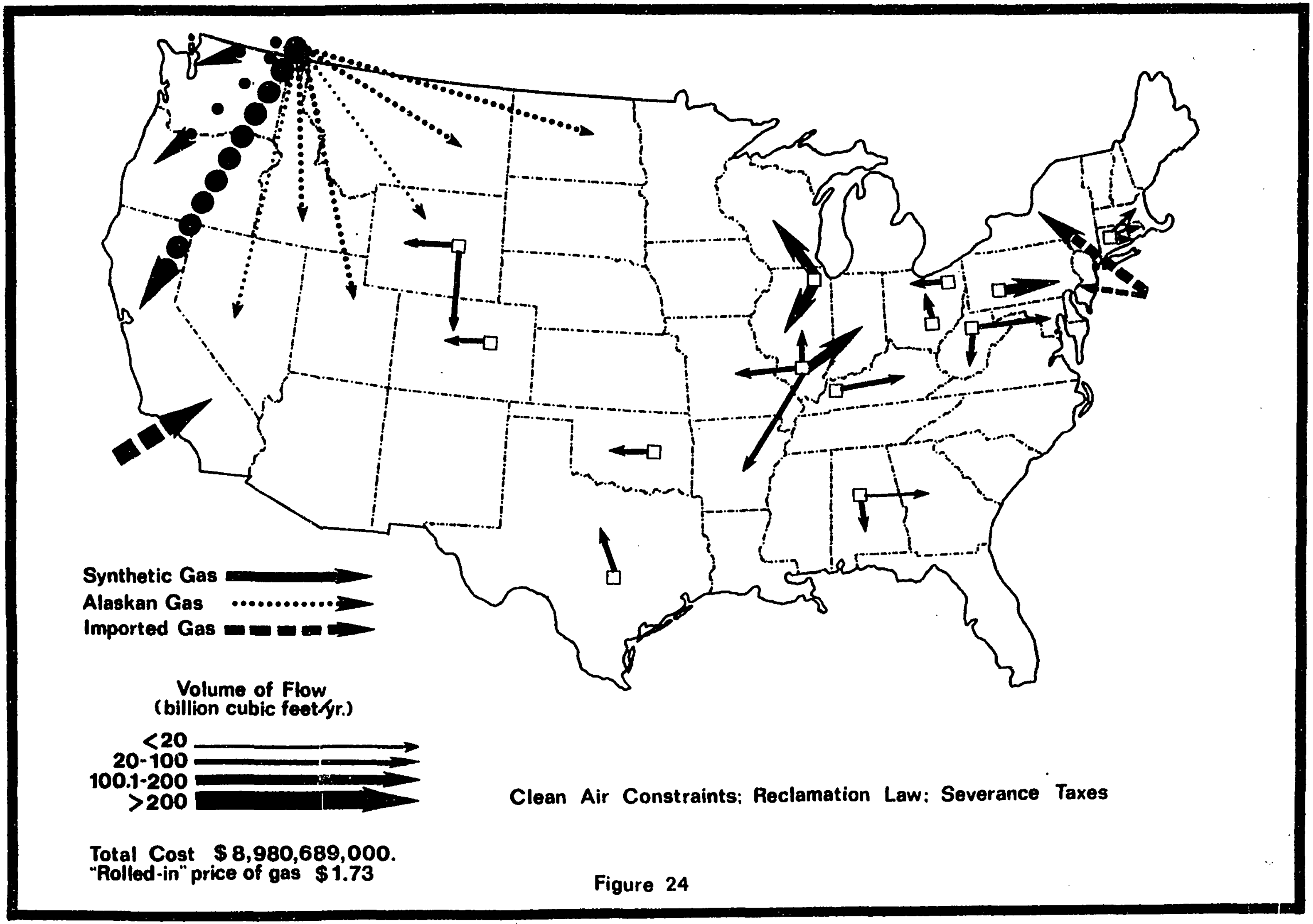
Finally, this result requires that two new facility sites, the Alabama and Oklahoma facilities, from among those not officially announced , be activated. These facilities, unlike the other unannounced sites, are located adjacent to large coal reserves and can be minemouth operations. They are also relatively close to large gaseous fuel markets.

Coal Gasification Deployment and Western Energy Development

Is western energy resource development essential to the attainment of an efficient and satisfactory synthetic gas supply system? The results from this model indicate otherwise. Consider additional variations of the previous simulation(which mirrors much of the relevant characteristics of the expected supply system). The fifty-mile Class I Clean Air "buffer zones" described in chapter 5 are employed to eliminate certain potential gasification sites. A simulation is conducted adding this constraint to the conditions of the simulation last described. The results are shown in Figure 24.

Despite the addition of severance taxes, the reclamation law, and stringent Clean Air "buffer zones", the total cost of the system is only $99 million per year greater than the totally unconstrained system in chapter 4. This cost computes to an average increase of less than one cent per Mcf, an insignificant increase. Thus, a national system could be planned taking these additional considerations into account without significantly increasing the cost of gas to the consumer.

Compared to the baseline case which employs seven facility sites in the West, Figure 24 only utilizes two gasification facilities in the region, one in Denver and the other in central Wyoming. Interestingly, western energy

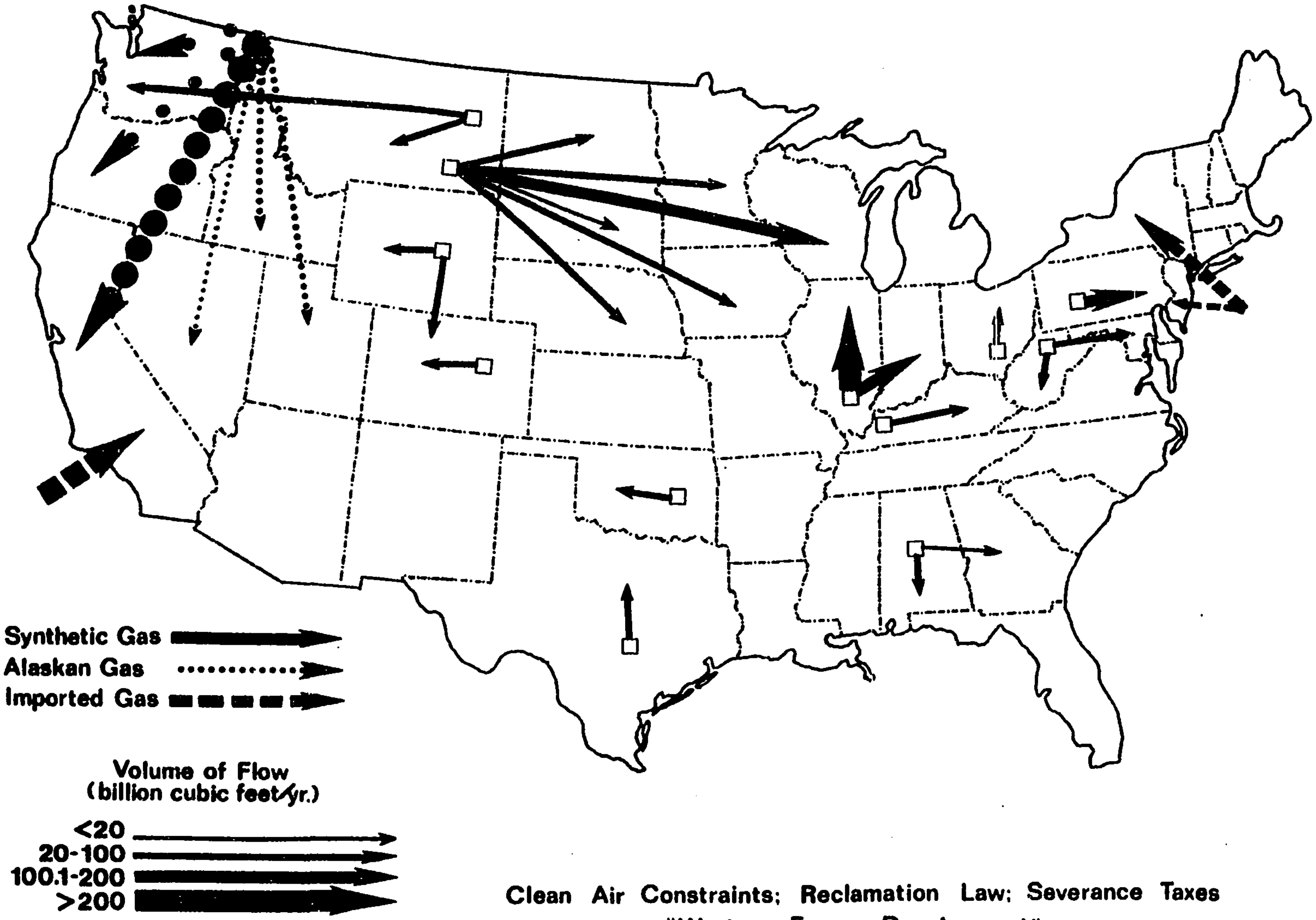


Clean Air Constraints; Reclamation Law; Severance Taxes

Figure 24

resources account for less than ten percent of the synthetic gas production needed to satisfy demand. The two gasification plants required in the West will not result in severe impacts for the region. No transfers of synthetic fuel to markets outside the West occur, and only Colorado and Wyoming are served with the product of western facilities. The Northeastern and Middle Western states of Kentucky, Illinois, Ohio, Pennsylvania, and West Virginia are the largest producers of synthetic gas, accounting for 74 percent of the national total. This simulation shows that even by following tough ambient air limitations, the heavy consuming areas are capable of making a substantial contribution to their gaseous fuel deficit. Such results again contradict the assumption that massive western energy resource development is a prerequisite for assuring greater gaseous fuel self-sufficiency. However, the addition of three new facility sites(Alabama, Oklahoma, and Chicago) are essential for synthetic fuel development to generally avoid western sites.

A comparison with these results can be made to a simulation in which a conscious policy is geared to develop all announced western gasification sites not excluded by Clean Air buffer zones. Such a policy is viewed by equating all remaining western sites to capacity. The optimum solution for this simulation, shown in Figure 25, incurs annual additional costs of $232 million over the identical case that does not consciously develop western energy resources.



Total Cost $9,132,819,000.
"Rolled-in" price of gas $1.74

Clean Air Constraints; Reclamation Law; Severance Taxes
"Western Energy Development"

Figure 25

This activates two previously unnecessary sites. The southern Montana site processes 328 billion cubic feet of synthetic gas annually. By utilizing western coal, three eastern sites would not be utilized(Chicago, Northeastern Ohio, and Connecticut). Consumers are forced to pay high Montana severance taxes and high transport costs for transporting minemouth SNG from that state to the upper Middle West. The northeastern Montana facility provides the state of Washington with 84 billion cubic feet of gas annually. By utilizing western energy resources, fewer load-center sites are employed, resulting in long distance gas transmission in many cases. Moreover, most of the gas produced in the West is transported outside the region, little remains for local use. Thus, the area consuming the fuel is not subject to the deleterious impacts of the facilities.

The costs of a western oriented policy could be quite expensive to certain utilities and particular demand areas, particularly if the gasification facilities are located in a state with a high severance tax. For instance,assume that a Wisconsin utility employs a coal gasification plant in southeastern Montana to provide 119 billion cubic feet of SNG to the state(see Figure 25). Because of the high Montana severance tax, reclamation law fees, and large transport costs incurred for shipping the SNG to the market, the synthetic fuel would cost approximately $3.62 per Mcf. This 119 billion cubic feet represents 34 percent of the states' 1985 FEA estimated gaseous fuel demand. The spatial-allocation model shows that the remainder is supplied from domestic natural gas supplies. Rolling-in the price of SNG to the assumed price of $1.55 per Mcf for the domestic gas results in an average price of $2.62 per Mcf for all gas provided by the utility. Such a price may be unacceptably high to the consumers of gas in that state compared to prices for gas elsewhere. As shown, an effort to develop western energy resources for SNG production within the given policy system may result in prices unacceptable to some utilities. A conscious policy to develop western energy resources for these needs may necessitate an interference with the market system.

Conclusion

The results of the simulations investigated in this chapter show that any policy that aims to confine the siting of coal gasification facilities to particular locations (i.e., "market-oriented", "western-oriented") will incur higher total costs than other siting strategies that have more locational flexibility, *ceteris paribus*. Table 8 compares the principal simulations presented in this chapter. The "market-oriented" and "western-oriented" policies

Table 8: Comparison of Chapter Six Simulations*

Simulation	Total Costs (in thousands)	Increase in Total Costs (in thousands)	Number of Sites
Baseline	$8,882,153.	0	14
Additional Sites	$8,940,717.	$58,564.	11
Additional Sites, Clean Air "buffer-zones"	$8,980,689.	$98,536.	13
Western-Oriented , Clean Air "buffer-Zones"	$9,132,819.	$250,666.	12
"Market-Oriented"	$9,468,753.	$586,600.	11

*All simulations except for the Baseline case have severance taxes and the effects of the reclamation law included.

(with severance taxes and the reclamation law) are the most expensive solutions. The "market-oriented" solution incurs the greatest costs for the system as a whole as it is more expensive to haul coal than it is to transport gas. The table also indicates that solutions which use fewer sites incur higher costs.

CHAPTER VII

AN EVALUATION OF SITING STRATEGIES

Introduction

The previous two chapters demonstrated that various existing conditions and different policy goals could be incorporated into the spatial allocation model by adding new constraints and by adjusting parameters. In this chapter, this information is used to compare and evaluate alternative siting strategies and to enumerate specific siting recommendations to achieve certain policy goals.

Gasification facility siting can be classified according to the overall siting pattern employed and where the facilities are located with respect to the resources and load centers. Siting patterns can range from an extreme "concentration" of facilities to a "dispersed" pattern in which numerous facilities are activated over a broader area. In addition, the gasification facilities themselves can be located at the minemouth, adjacent to the demand center, or at an intermediate location. This classification is illustrated in Table 9. Each of the possible siting alternatives presented have specific advantages and disadvantages associated with them.

Table 9: Possible Siting Options

Location of Conversion Facility	Siting Pattern	
	Concentrated	Dispersed
Minemouth		
Intermediate		
Load center		
Minemouth, Intermediate, Load center		

As noted in the previous chapter, different siting strategies lead to different impacts and generally instigate different levels of opposition and support. Different siting alternatives can be evaluated in many ways. Important criteria include: (1) the efficiency of the solution (economic cost, ability to satisfy demand); (2) the equity of the solution (Who gets what, where? How are impacts, costs, and benefits distributed?; How are the risks distributed?); (3) the flexibility of the solution (Can the siting alternative respond to changing conditions?); and (4) the reliability of the solution (How certain is it that gaseous fuel can be continuously supplied under different conditions and events?).

Although it is possible to incorporate some of these criteria explicitly into the model(see, e.g., Austin, Smith, and Wolpert, 1970; Holmes, Williams, and Brown, 1972; Khumawala, 1973; Morrill and Symons, 1977; Orloff, 1977; White and Case, 1974), they are evaluated qualitatively in this study.

Because the model can portray an infinite number of siting strategies, it is necessary to focus attention upon particular cases that may represent prototype siting strategies of general interest to policymakers. Therefore, the following siting strategies are compared and evaluated: (1) "coal gasification parks"; (2) a "dispersed" siting strategy; (3) a "market oriented" location strategy; and (4) a "western oriented" siting strategy. The "western oriented" siting strategy is chosen since it represents a heated policy to locate the facilities in a particular energy-rich region of the country which does not itself need additional fuel supplies. These strategies represent extreme cases which can be compared and evaluated so that more moderate siting strategies can be pursued.

Since the "market oriented" siting strategy for "baseline" conditions was presented in the previous chapter, it is not necessary to elaborate on it further. However, it is necessary to briefly illustrate the affects of pursuing an "energy park", "dispersed", or "western oriented" siting strategy.

Coal Gasification Parks

Concentrating the gasification facilities in a few sites can reduce the overall political opposition and limit the number of people adversely affected by them(see, e.g., Wilbanks, 1977). Coal gasification parks can be set aside in areas that are receptive to the siting of new energy facilities. Proponents of this type of siting strategy note that it would be easier to obtain licenses for a few large facility sites than it would for a larger number of dispersed sites. Moreover, the construction workers can stay in the area longer, beginning construction on a new facility as one is completed. Thus, the local communities would be better able to accommodate this population if it were less transient(National Science Foundation, 1974). Therefore, political opposition may be substantially reduced by such a siting strategy. Some areas are in favor of large scale energy development and could be prime sites for such energy parks. For instance, Utah is eager to become an energy exporting state and has admonished EPA for imposing strict air guidelines that reduce the number of acceptable facility sites that are available(Gill, 1976). West Virginia and Oklahoma have also expressed some willingness to become regional energy centers.

A gasification park simulation identifies the feasibility of employing three large energy parks as the principal suppliers of synthetic fuel in the nation. Using the same fundamental constraints of simulation 6(Chapter 4), (except that severance taxes and the affects of the reclamation law were incorporated), the maximum flows, u_i, for these facility sites were raised to infinity. The optimum solution, shown in Figure 26, only utilized the West Virginia and Oklahoma sites as the Utah site was found unnecessary. This concentrated siting strategy was found to be only $742 thousand more expensive than the unconstrained solution. This amount computed for the entire system is negligible. Therefore, in terms of operating and transportation costs, the concentrated siting strategy is an extremely efficient solution.

The optimum solution did not include the Utah site despite that states' interest in promoting energy development. Because of Utah's strong prodevelopment position and large coal reserves, a national policy could designate that state as an "energy sacrifice area" and relax all federally imposed environmental controls restricting development. For general interest, a simulation was conducted in which only the Utah site was utilized(as the activity for the West Virginia and Oklahoma sites was set at zero). Such a policy could satisfy national gaseous fuel demand but would be $81 million per year more expensive than the previous concentrated pattern that included the other two "energy parks". This additional cost

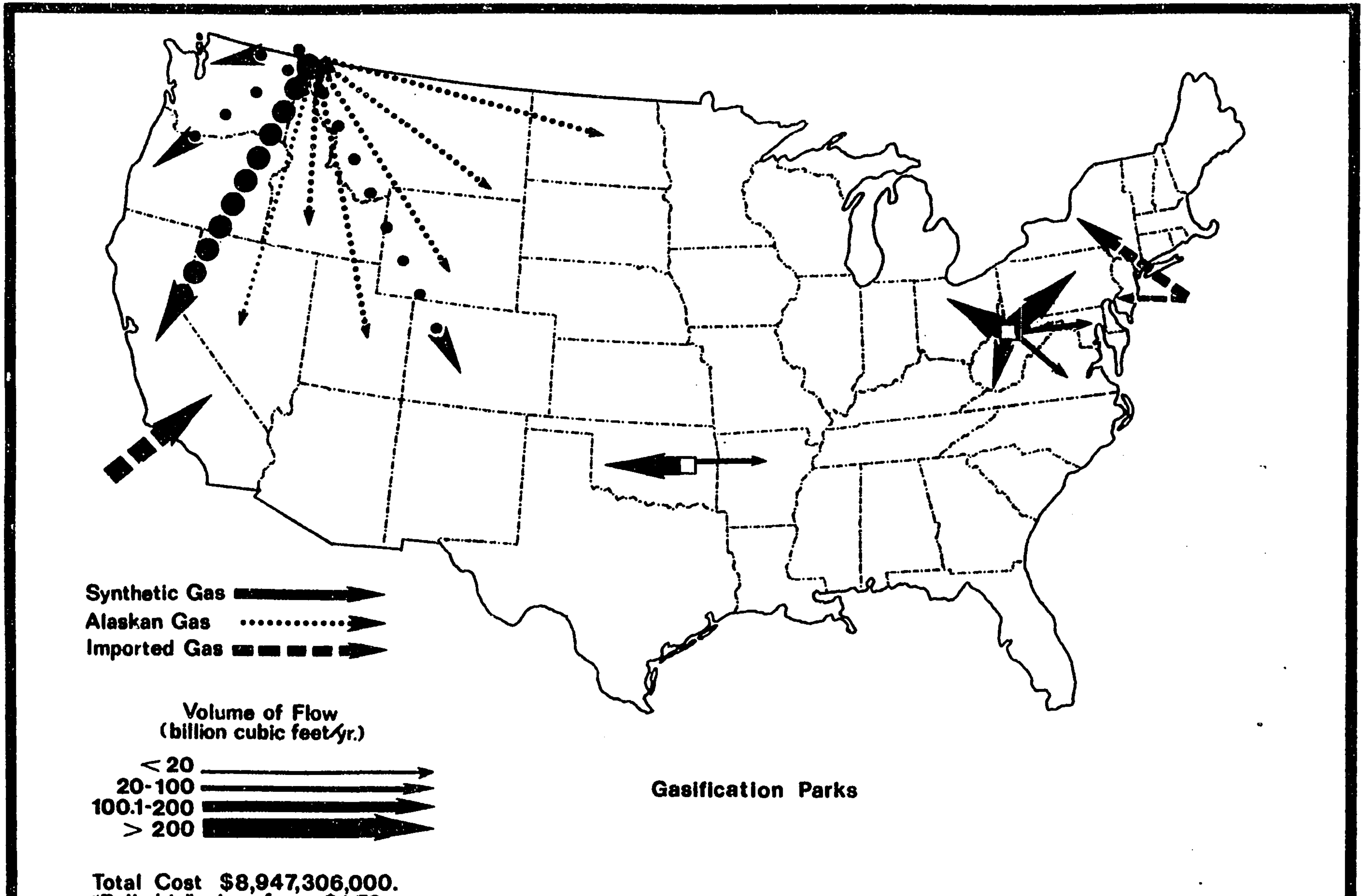

Synthetic Gas
Alaskan Gas
Imported Gas
Volume of Flow
(billion cubic feet/yr.)
< 20
20-100
100.1-200
> 200
Total Cost $8,947,306,000.
"Rolled-in" price of gas $1.73
Gasification Parks

Figure 26

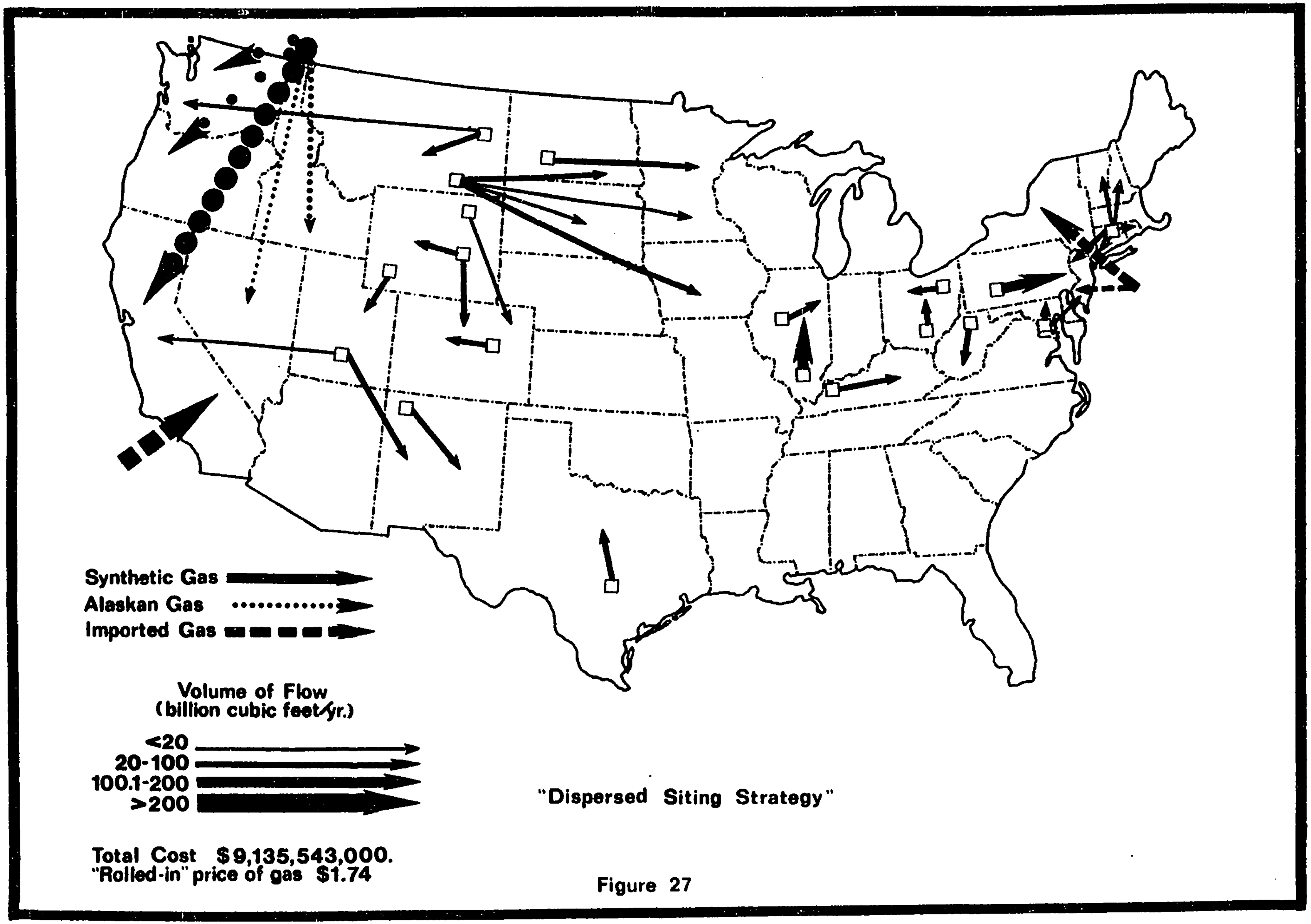
is not so high to preclude a consideration of pursuing this siting strategy. With this case, Utah would have all twenty-one gasification facilities while the rest of the nation would not require any.

The "energy parks" simulations greatly reduce the overall transportation costs incurred in the synthetic gas supply system because no long distance transport of fuel is necessary (interregional shifts of fuel are employed). Also, sites are chosen that are in important gas marketing areas. West Virginia can easily service the large Pennsylvania and Ohio markets and Oklahoma is close to the high Oklahoma-Texas market.

Dispersed Siting Strategy

The opposite approach to the "energy parks" strategy is to evenly disperse the facilities so that instead of having a small number of people subject to the large impacts of concentrated facilities, many people are subject to a smaller level of impact. Dispersing facilities evenly throughout the nation is not possible for some types of energy facilities, such as oil shale retorts, that are based upon locally occurring resources. However, coal reserves are rather ubiquitious and coal gasification facilities can be located in many places throughout the country.

The simulation illustrated in Figure 27 assumes that



"Dispersed Siting Strategy"

Figure 27

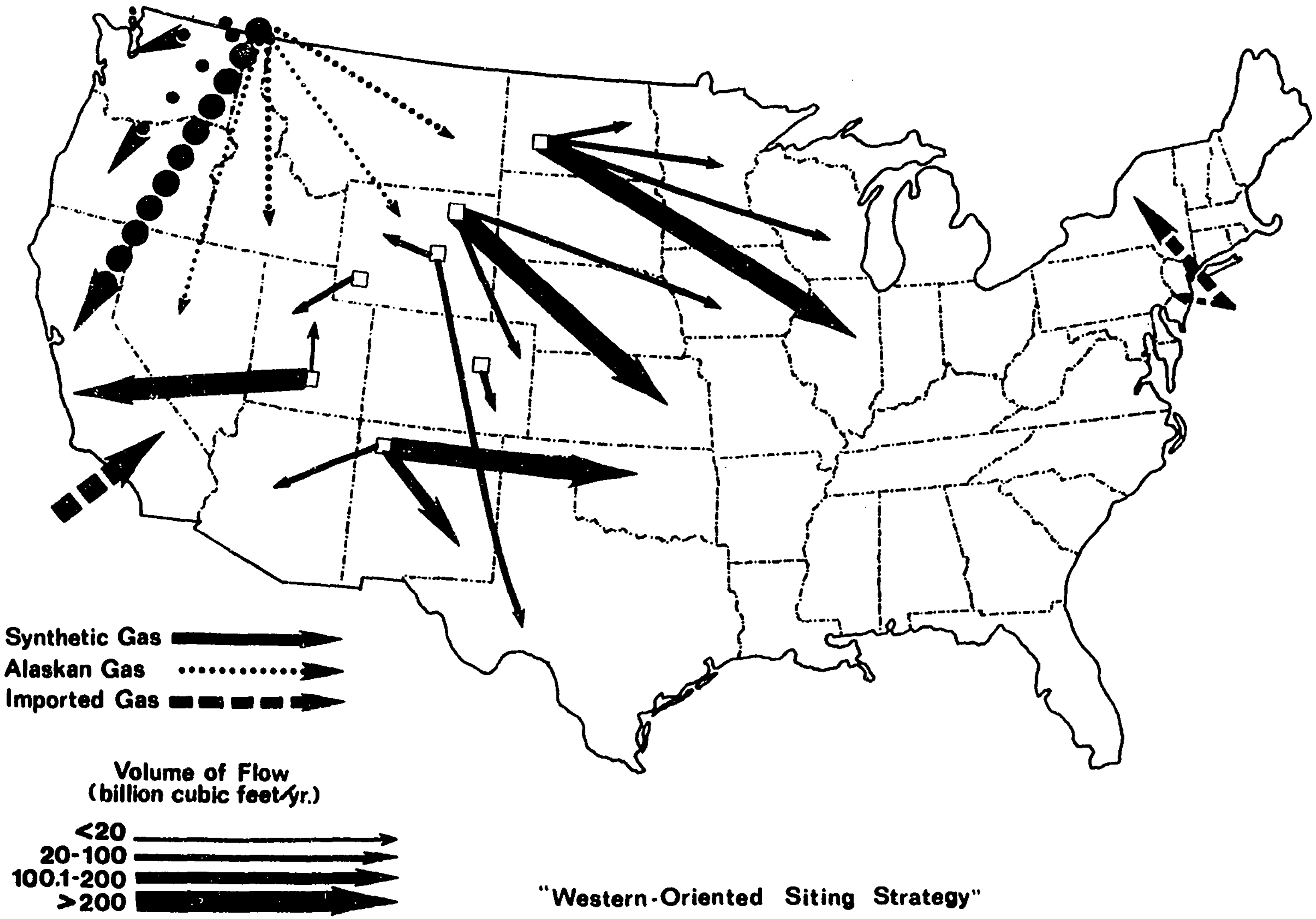
every announced gasification facility site has at least one operating standard-size facility. The cost of this strategy exceeds the "energy park" results by $188 million per year. Commercializing all facilities increases overall transportation costs and requires that some less than optimal facilities, such as the Connecticut and Maryland sites, be utilized. However, the differences between these results and the "energy park" solution computes to only about one cent per Mcf.

Western Oriented Location Strategy

Figure 28 shows the results of a simulation in which all gasification sites announced in the West operate at capacity and portrays a policy to exclusively use western energy resources. These results are $77 million per year more expensive than the "energy park" results. Such a siting strategy is likely to meet with severe political opposition from groups and individuals in the West.

Market Oriented Location Strategy

A market oriented gasification siting strategy was shown in Chapter 6. This siting pattern costs approximately $356 million per year greater than the modified base case. The optimal solution to this simulation, shown in Figure 22 utilized the Connecticut, Maryland, Pennsylvania, Ohio, Chicago, Los Angeles, and Seattle sites. Despite the activity



"Western-Oriented Siting Strategy"

Total Cost $9,023,843,000.
"Rolled-in" price of gas $1.74

Figure 28

of these facility sites, it was necessary to activate the West Virginia and Texas sites to satisfy gaseous fuel demand.

A Comparison of Results

The spatial allocation model provides a framework within which to compare alternative siting strategies. The criteria used to evaluate the alternatives in this study were basically related to the efficiency of the solution. However, other criteria could also be used to evaluate the results. Because of the unspecified nature of many of the criteria, these judgements will be expressed subjectively rather than quantitatively. After evaluating the options, recommendations for siting these facilities can be presented.

Efficiency

Efficiency can be measured in several ways. Because of the structure of the model, many of the attributes of this criterion are already accounted for. For instance, the conservation of flow equation guarantees that no conversion facility produces more synthetic gas than is necessary to satisfy demand. Likewise, the model defines flows that do not produce bottlenecks.

In terms of minimizing overall transportation costs to the system, the "clustered" siting pattern is most efficient.

As shown in Table 10, this solution incurs approximately the same price for synthetic, Alaskan, and imported gas as the base case, $2.92 per Mcf. The opposite siting strategy, dispersing them as much as possible, is $188 million per year more expensive. The "market oriented" siting option is the most expensive of the four, resulting in a price of nondomestically produced natural gas at $3.04 per Mcf. This option is much more expensive since it requires long distance coal transportation for many large urban-based facilities. The "western oriented" siting strategy, costing about $77 million per year more than the clustered pattern, is not "unacceptably" expensive.

The "concentrated" location strategies are most attractive if the policy emphasis is to minimize the total costs of the system. Any effort to disperse facilities more evenly incurs additional transport costs. Policies emphasizing a particular region of the country, such as the "western oriented" option, necessarily increase the transport costs for the system as a whole. These siting strategies require the utilization of expensive sites and necessitate long distance synthetic gas transport. The most expensive siting options are "market oriented" strategies that require "strip and ship" development patterns with long-distance coal shipments.

While the costs of these options range considerably,

Table 10: A Comparison of System Efficiency

Simulation	Cost of synthetic, imported, and Alaskan gas (in thousands of dollars)	Cost per Mcf
Base case	8,946,564.	$2.92
Concentrated	8,947,306.	$2.92
Western Oriented	9,023,843.	$2.96
Dispered	9,135,543.	$2.98
Market Oriented	9,302,564.	$3.04

None is too expensive to be rejected as a possible siting strategy. For instance, the rolled-in price of gas for the market oriented siting strategy is $1.75 per Mcf, only two cents above that of the "concentrated" siting option. However, because the increased costs incurred by this system do not fall evenly upon all gasification sites and markets, it is necessary for some federal legislation to distribute these costs among all customers before this strategy becomes possible.

Equity

Although the "equity" of the solutions can be measured in many ways, a critical consideration in deploying new energy supply facilities is the regional equitability of the distribution of the facilities and the dependence of some regions on others. If facilities are sited in one region and the gas consumed in another, regional conflict could occur. Furthermore, antagonism could arise if the impacts of the facilities are felt in one region while the fuel goes to another.

It was shown in Chapter two that conflict has already arisen between the southern energy producing states and the northern consuming states. Likewise, some westerners, who are self-sufficient for most energy needs, do not feel it fair that western energy be rapidly developed to satisfy growing energy demand elsewhere.

Coal gasification siting strategies can aggrevate or reduce these incipient interregional rivalries. An attempt to follow equitable siting options may encourage interregional cooperation. Southern states, for example, may be more willing to send natural gas to the north if the north demonstrates a commitment to energy production by constructing coal gasification facilities in the area. Although these facilities may not provide the bulk of the region's gaseous fuel needs, the gesture may go far in promoting interregional cooperation.

The "energy park" and "market oriented" siting strategies appear to be the most equitable of the four siting options considered. However, equitability is a subjective term depending upon individual preferences. The "energy park" simulation, although not activating many gasification sites in the Northeast, requires that the West Virginia gasification park produce 994 billion cubic feet of synthetic gas annually. This is 342 billion cubic feet above the announced gasification capacity for the Northeast.[1]

Despite the vast size of the "park", it would only provide about 25 percent of the region's gaseous fuel needs. Assuming LNG imports of 200 billion cubic feet, the Northeast would still be importing about 65 percent of its gaseous fuel from the south. This siting option, however, makes the Northeast least dependent upon other region's gas. In this light, it is somewhat equitable.

The "market oriented" siting option may be the most equitable of the solutions considered. According to this option, the area consuming the gas suffers the impacts of the facilities. There is some evidence that this siting pattern may reduce some of the conflicts associated with energy facility siting. For instance, the National Coal Policy Project's task force on air pollution, composed of industrialists and environmentalists, is close to reaching a consensus position that new coal-fired power plants be sited near the load centers(Carter, 1977:276). The equitability of the strategy sounds clear.

However, the gasification facilities would still require coal from the resource area. The supply area would be subject to the impacts of the extraction facilities and be inconvenienced by constant unit-train movements. Moreover, the gasification facilities would bring some positive benefits to the resource area, principally because of the large workforce the facilities require. Incoming people bring economic growth, a larger tax base, more jobs, and more revenues to isolated coal supply areas. Some growth-minded groups may be willing to accept the undesirable impacts of gasification facilities in return for the economic expansion and property tax revenues guaranteed with population increases. The West Virginia gasification park, for instance, would create 56,000 construction related jobs(Carasso, 1975:6-31). Such a project could be encouraged in areas of high unemployment and slow growth.

A "strip and ship" siting option, while sounding equitable, may strengthen charges that the resource area is being exploited. An "equitable" siting option must evaluate such considerations.

The "western oriented" and "dispersed" patterns force the West to produce more gaseous fuel than it needs. In the "western oriented" case, no area outside the West suffers the undesirable impacts of the facilities. The "dispersed" siting option is more "equitable" in this regard but the West still is a major exporter of gaseous fuel. However, certain groups may prefer such a siting option in lieu of the economic benefits associated with locating these facilities in remote areas.

Coal gasification facilities are not subject to the large catastrophic risks of nuclear power plants(meltdowns) or hydroelectric dams(failures) but are subject to the chronic risks of continuous emissions and workplace hazards(Hohensemser, Kasperson, and Kates,1977). Because emissions are converted into impacts as they interact with conditions at a particular site, siting options can provide a means to reduce the risk associated with deploying these new technologies. A concentration of facilities will substantially increase the risk to the people living in the local area, but since these gasification parks are sited in remote areas, the overall mortality risk to the nation as a whole is low. A "dispersed" siting configuration decreases the level of emissions from any one site, but subjects most of the inhabitants of the nation to a higher increment of air pollution, thereby possibly resulting in an increase in the overall mortality risk. A "market oriented" siting strategy, unless combined with a vigorous emission "offset" policy, will enhance the risk to the load-center cities. A "resource oriented" siting pattern may decrease the overall risk because (1) most resource areas have low ambient air pollution levels and a small increase of pollution will not substantially increase the mortality risk to the local inhabitants; (2) most resource areas, and particularly the West, are rather sparcely populated and few people will be subject to increasing environmental hazards. Therefore, it appears that a minemouth siting strategy will have a lower total risk associated with it than a load-center option. Furthermore, a concentration of facilities will have a lower absolute amount of risk than a dispersed siting configuration.

Flexibility

Certain facility siting options are more tied to specific existing institutional and global conditions than are others. Gasification technologies in general, however, are somewhat dependent upon an elevated world price for oil. However, locating the facilities so that costs are minimized can reduce this dependency somewhat. Therefore, the "concentrated" siting pattern may be more "flexible" in the sense that it may be better able to withstand the effects of decreases in the price of alternative fuels.

In many other ways, though, the "concentrated" siting option may be less flexible than desired. The huge infrastructural investment at one site makes the "park" heavily dependent upon the initial conditions that made the site attractive in the first place. The resources and reserves in the area must be carefully assessed to guarantee that the facilities can operate efficiently and inexpensively for a long time. "Energy parks" can not shift to other energy rich areas as resources are depleted. The construction of a large gasification park capable of producing close to one tcf/day for several decades requires a careful assessment of the natural and human resources in the area. Moreover, a change in laws or attitudes in the host energy park state can alter the attractiveness of the site. Ex post facto legal changes could be expensive once the large investments in coal gasification parks are made.

A more dispersed siting pattern is more flexible in this regard. Particular events affecting one site need not have a great impact on the supply system as a whole. It is not as essential to carefully assess the resources in the area if only a small facility is to be located there. The depletion of fuel reserves in the area will not harm supply to the system as a whole. Therefore, the more dispersed the siting pattern, the more flexible the supply system.

Reliability

A major concern of most gas utilities is the provision of reliable service. The "mandate to serve" doctrine holds that utilities must provide reliable service or else lose their franchise.[1] Therefore, an important consideration in siting coal gasification facilities is to have a reliable supply of synthetic gas.

As noted earlier, synthetic gas supply systems can not be as reliable as natural gas supply systems since the

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[1]For an interesting discussion of this concept, see Murdock, 1977).

process requires the transport, handling, and processing of discrete shipments of coal. However, reliability does depend somewhat on the particular siting strategy followed. For instance, it was shown earlier that locating many gasification facilities in the UMW controlled areas of the east could result in sudden gas stoppages resulting from miner's strikes.

Clustering gasification facilities into gasification parks will decrease the reliability of the supply system to some degree. Although the gasification park, as a great investment, will probably run more efficiently than other individual facilities during most normal conditions, many possible events could occur to temporarily or permanently close the "park" and halt gaseous fuel supplies to a large market. The closing of a single dispersed gasification facility will not bring much hardship to the nation, but the abrupt stoppage of 10 to 12 gasification facilities at one location could have catastrophic impacts for a fuel dependent region. Any changes in the laws affecting the energy park site could ruin the competitiveness of the site. Of more concern are regulations that may force a closure of the facility. For instance, if an endangered species is found adjacent to an operating gasification park, courts may order the facility closed, thereby cutting off gaseous fuel supplies to millions of customers.[1] In addition, an act of terrorism or sabotage directed at such an energy center could also shut down the operation, affecting millions of people. A technical breakdown or disaster of some element at one of these parks, such as a power failure or fire, could cut off supplies from the park. In sum, having a large portion of the synthetic fuel supply concentrated in a few locations decreases the overall reliability of the fuel supply system.

Conclusion

The relationship among the location patterns and conversion facility site, on one hand, to the four evaluative criteria on the other, is illustrated in Figure 29. The location pattern and conversion facility location are shown as related to the efficiency, equity, reliability, and flexibility of the fuel supply system. Thus, the combined outcomes of individual location decisions affect the attributes of the synthetic fuel supply system as a whole. As shown in the figure, positive or negative relationships appear to exist among the configuration of gasification facilities and the evaluative criteria.

Therefore, a policy which, either through direct measures or indirect manifestations, results in a high amount of

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[1] P.L. 93-205; 87 Stat. 884; A District Court ordered a halt to construction of a partially completed dam in Tennessee illustrating the degree to which this law will be enforced (New York Times, 1977:24).

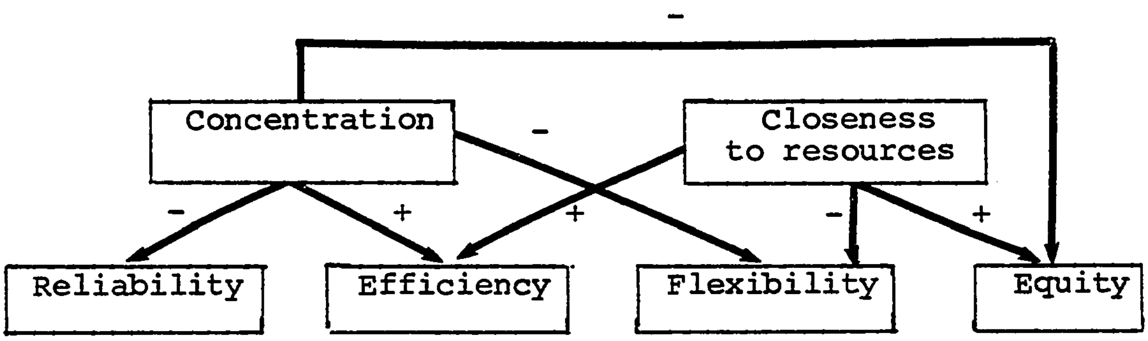

Figure 29: Effects of Different Patterns of Development

concentration and a high degree of minemouth location(synomonous with "location to resources") will result in a high absolute value for the evaluative criteria(of the appropriate sign). Thus, an extreme concentration of facilities adjacent to the resources will result in high levels of efficiency while sacrificing flexibility, equity, and reliability. On the other hand, dispersing facilities away from the resource areas will lower efficiency but increase the flexibility, equity, and reliability of the system. Increasing concentration but locating away from the resources increases and decreases the efficiency of the solution. This paradox is explained by examining the distribution of where the appropriate increases and decreases occur. Certain firms may find the results of such a plan efficient whereas others may not. The location of conversion facilities should not have overwhelming effects on reliability since only concentration is linked to reliability.

In conclusion, each alternative siting strategy has its own particular costs and benefits. These are:

(1) Mine-mouth conversion facility siting achieves great national economic benefits, particularly when a concentration of facilities is situated adjacent to large coal reserves. However, since most coal-rich areas are in isolated rural areas, the affect of such facilities could be disasterous on the local area. In particular, the large population influx necessary to construct and service new facilities would cause great social, economic, and political disruption and lead to a boom-bust pattern of development. Moreover, such a pattern would lead to a severe localization of adverse environmental impacts resulting from the emissions and requirements of gasification facilities. In addition, such a location strategy may lead to charges that the resource area was being exploited to satisfy the unnecessarily high levels of energy demand elsewhere.

(2)Dispersing the facilities throughout the country leads to a more equitable distribution of adverse environmental and social impacts but increases the total economic cost of synthetic gas supply to the nation. Since numerous facilities are spread throughout the country, such a system may also be more flexible to changing conditions or events affecting particular locations. Becuase no one area makes unreasonable sacrifices to supply others, such a siting policy could lead to greater harmony between different regions and reduce "sectionalistic" rivalries.

(3) Locating the coal gasification facilities near the markets is the most expensive supply alternative of the ones examined. Such a siting alternative may be the most equitable since the city needing the fuel suffers the adverse impacts associated with the facilities. The Clean Air "offset" policy may actually encourage load center sites as it permits polluting facilities to be located in a polluted region if other point sources of emissions can be reduced to result in an absolute improvement in air quality. Such a siting alternative may lead to a greater awareness among city residents of the importance of conserving fuel and decreasing consumption so that additional facilities are not sited nearby. This siting alternative also incurs the transportation problems involved in moving coal from the resource area to the cities.

(4) Although there are no public or private entities to plan or enforce a national siting strategy that can lead to an appropriate compromise between economic goals and social and environmental risks, individual participants can weigh such considerations on a case-by-case basis. The environmental impact statement, for example, requires that other feasible alternatives to the one proposed be considered. Vigorous attention to the spirit of the law would carefully evaluate different siting alternatives and their associated costs and benefits. National policy can be made to encourage or discourage certain siting

patterns. For instance, the Clean Air "offset" policy encourages an urban location for some facilities to some degree. Unilateral decisions made by states affect present siting decisions which can lead to inertia when future siting plans are made. It was shown that the steep Montana coal severance tax reduced that state's siting attractiveness. If presently planned facilities are located elsewhere, industrial inertia could lead to further expansion to locate in areas of present development rather than siting in Montana.

Recommendations for Further Research

As demonstrated in this study, spatial allocation modelling can be a useful tool for evaluating the effects of different policies and conditions on the synthetic and natural gas supply system in the United States. The model is useful in determining the "optimal" solution to location-allocation problems that have a large number of conflicting objectives(e.g., least cost and clean air). Further research applications of this type of anlaysis can provide an even stronger basis for determining the consequences of facility siting strategies. Such additional work should include: (1) improvements and refinements of the data; (2) improvements in the structure and goals of the model; and (3) extensions of the model to other applications.

Improvements and Refinements in the Data

Many improvements and refinements of the data base in this model are possible. First, the capacity constraints on the links and nodes in the system can be more adequately determined. For instance, little work has been directed in this study toward identifying the exact capacity of many of the pipeline and rail links. As demonstrated by Gauthier (1968) and Sa(1969), a capacitated network can provide different flows and solutions than one which is unconstrained. The sheer volume of links in the system will make such data compilations an arduous task. These data refinements will account better for the limitations of existing infrastructure in deploying new technologies and allow a more careful evaluation of the desirability of adding to the infrastructure to meet system needs.

Second, the assumptions made in this model about the gasification facility sites could be relaxed. Numerous additional sites other than those considered here could be added, allowing policymakers to evaluate a broader range of siting options. In addition, capacity restrictions on the gasification facility sites could be lifted to explore further the relative attractiveness of certain sites. Some sites, for example, may be optimal locations for many facilities in an efficient system.

Third, the scale of the model can be increased so that the solutions can be of more specific use to particular subregions within each state. In the present data base, each state's demand is assumed to occur at a single point (the population centroid). Although this assumption of point markets can produce information that is of immense help to state and regional planners, a further disaggregation of the location of demand may provide more accurate information to policymakers and would be more theoretically rigorous.

Similarly, point locations are also used to represent the location of coal resources. Disaggregation of these data could be performed in order to provide more specific information about coal flows and transport.

Improvements in the Technical Structure of the Model

Further work could also improve the technical structure of the model. Additional refinements can be made, for instance, to incorporate explicitly into the model policy goals other than system efficiency. The formulation in this study expresses other planning objectives in the form of linear constraints. Budding research in geography has suggested the analytical tractability of other goals, such as equity and accessibility considerations in solving more localized facility location problems(e.g., Orloff, 1977; Holmes, Williams, and Brown, 1972; and Khumawala, 1973).

It is also difficult to convert qualitative decisionmaking criteria into quantitative terms given the structure of the model. The political resistance to opening a certain facility or the national defense risk in an overconcentration of facilities are problems that are not easily handled by spatial allocation formulations(see, e.g., Austin, Smith, and Wolpert, 1970). Additional research could further define ways in which qualitative considerations can be incorporated quantitatively into the model.

Further work can employ other algorithms to see if a more efficient siting pattern could be obtained by not restricting facilities to certain sites and by not assuming point markets. Church and Meadows(1977), for example, show that the optimal solutions to the p-median problem(see, e.g., Hakimi, 1964; Khumawala, 1964; and Hillsman and Rushton, 1975) can be obtained more efficiently when the facilities are not restricted to particular nodes. Thus, markets which have a significant fraction of demand a large distance from the closest facility could be served by other adjacent or additional facilities. Such a procedure may produce a feasible solution when none exists for the comparable restricted problem(Church and Meadows, 1977:373). Since this study problem includes a small set of possible facility sites, unrestricted nodal placement should result in a more efficient solution than in the restricted case(Church and Meadows, 1977:373). The computational demand of this type of analysis may create a severe barrier because of the large size of the study problem.

Some efforts have attempted to find better ways to convert "areas" into "points" for use in network programming models(see, e.g., Love, 1972; Wesolowsky, 1973:105-107). This study, as most network programming studies, has employed "centroids" as surrogates for the location of supply and demand occurring over an area. Recent efforts to convert "areas" into "points" subdivide areas into subregions having a uniform distribution of the measured phenomena. Distances between facilities and these regional subdivisions generate less error but expand the size of the problem. In this study, the use of state population centroids as a surrogate for the location of a particular state's demand is expeditious but is somewhat ludicrous. Some states, such as California, have prime market areas in two distinct locations. The state population centroid, located between Los Angeles and San Francisco, is not a major demand center at all. Continuing work can be directed toward reducing the assumption of point market areas that represent each state's fuel demand and each coal resource supply.

The present spatial allocation model assumes that the production costs from the mines and gasification facilities are linear. This implies that economies and diseconomies of scale are irrelevant in determining the distribution and activity of coal gasification facilities. Such considerations have been shown to be important in affecting the optimal locations of facilities(see, e.g., Cigno, 1971). Osleeb and Cromley(1977) demonstrate that more realistic solutions to multifacility problems can be obtained if the spatial variation in production costs and economies of scale factors are considered. This improvement in the model will be hampered by difficulties in determining the variation in production costs and scale economies of new gasification facilities for which there is little baseline data. Additional modelling, however, may provide a basis for further improvements of the model along these lines.

Additional work can also consider price-sensitive demand. The present model, by finding an optimum subject to a fixed demand requirement, assumes that the demand for gas for each state is not elastic with respect to the cost of obtaining that service. Although the literature abounds in facility location models that recognize the effect of distance on service(see, e.g., Holmes, Williams, and Brown, 1972; Khumawala, 1973), few models explicitly incorporate such factors into the objective function. Wagner and Falkson(1975) present a location model that does explictly account for price-elastic demand functions. If such formulations are combined with energy demand modelling, it may be possible to better analyze the substitutability of fuel from different sources.

Extensions of the Model to Other Applications

In further applications, the spatial allocation model can be extended in three major ways. First, although the model is concerned only with the gaseous fuel supply system, it could be expanded to include other fuel supply systems as well. This would enable the investigator to identify relationships with the location pattern of other types of energy facilities not considered here. For instance, the location alternatives for siting oil shale facilities, synthoil facilities, and other energy supply facilities in the United States could be examined. This would provide a means to examine the substitutability of energy forms under different policies and conditions. If comprehensively constructed and properly formulated, such a model could provide a stronger basis for national energy planning.

Second, the spatial allocation model in this study views possible future configurations of coal gasification facilities in static terms. Such results are informative in that they compare how the "on-line" system can look and what its costs and benefits will be if certain policy goals are pursued. However, the results do not show the "best" plan for siting these facilities consecutively through time, even though it is highly unlikely that all sites would be developed at the same time. A dynamic programming model(see, e.g., Taha, 1976: 208-238) could be utilized to select the best "plan" for consecutively siting the facilities so that overall costs are minimized.

Third, the model can be extended to provide information on the expected environmental impacts of different siting patterns. The expected emissions of energy supply facilities have been estimated(Science and Public Policy, 1975). This information can be combined with knowledge about different facility sites to estimate the level of impacts that a particular siting strategy may incur. This additional information can allow policymakers to compare the economic costs and environmental impacts of different siting strategies both for particular areas and to the nation as a whole. Such knowledge could provide a better basis upon which to compare different siting policies and can reduce many of the uncertainties likely to arise.

Conclusion

In sum, it has been demonstrated that the spatial allocation model framework can provide a basis for national and regional energy planning. Because of the scope of the model, refinements could be continuously made as additional information on the technologies and the policy system becomes available. Further refinements of the model can increase its credibility and predictive power so that it can be a stronger planning tool. Such a model can help in evaluating sites for new energy facilities and to develop fuel supply systems that correspond to a range of often-conflicting policy goals.

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Appendix "A": Annual Coal Supply per State *
(in 10^{14} Btu's)

State	Underground	Strip	Total annual Coal Supply
Alabama	15.6	30.3	45.9
Arizona	0	25.0	25.0
Arkansas	0	3.1	3.1
Colorado	84.8	117.5	202.3
Georgia	0	0.1	0.1
Illinois	76.8	66.7	143.5
Indiana	0.3	41.6	41.9
Iowa	0	7.9	7.9
Kansas	0	1.6	1.6
E. Kentucky	18.5	20.5	39.0
W. Kentucky	4.1	5.2	9.3
Michigan	0	0.3	0.3
Missouri	0	15.6	15.6
Montana	0	205.1	205.1
New Mexico	7.2	56.0	63.2
N. Carolina	0	0.1	0.1
N. Dakota	0	220.1	220.1
Ohio	16.2	30.9	47.1
Oklahoma	0	4.7	4.7
Oregon	0	0.1	0.1
Pennsylvania	30.4	26.4	56.8
Pa. (anthracite)	20.0	2.4	22.4
S. Dakota	0	1.4	1.4
Tennessee	0.6	1.0	1.6
Texas	0	97.8	97.8
Utah	27.4	0	27.4
Virginia	7.6	3.9	11.5
Washington	0	8.7	8.7
W. Virginia	133.5	31.5	165.0
Wyoming	0	151.0	151.0

*Assuming 50 percent recovery
Source: Battelle Pacific Northwest Laboratories, The Regional Analysis of the U.S. Electric Power Industry, Volume 4a, 1975.

Appendix "B": Estimated Gaseous Fuel Demand per State

State	Consumption 1974[a]	% National Total	1985 Demand[a]	
			FEA	Ford Foundation
Maine	1.9	.01	2	3
New Hampshire	8.1	.04	9	13
Vermont	1.9	.01	2	3
Connecticut	66.3	.30	70	97
Massachusetts	155.2	.74	173	239
Rhode Island	23.8	.11	26	36
New Jersey	275.1	1.49	349	482
New York	627.5	3.12	730	1,010
Pennsylvania	715.6	3.79	887	1,226
Illinois	1,163.2	5.45	1,275	1,764
Indiana	531.8	2.64	618	854
Michigan	816.9	3.90	913	1,262
Ohio	1,086.7	5.19	1,215	1,679
Wisconsin	381.1	1.87	437	605
Iowa	367.6	1.53	358	495
Kansas	630.4	2.83	662	916
Minnesota	351.6	1.59	372	515
Missouri	409.9	1.94	454	628
Nebraska	223.3	1.05	246	340
North Dakota	38.0	.17	40	55
South Dakota	32.0	.16	37	52
Delaware	20.4	.11	26	36
Florida	292.9	1.34	317	434
Georgia	330.3	1.57	369	508
Maryland(D.C.)	199.3	.95	223	307
North Carolina	140.2	.75	176	243
South Carolina	132.0	.68	160	220
Virginia	141.7	.72	169	233
West Virginia	192.0	.91	214	294
Alabama	275.3	1.27	297	411
Kentucky	233.6	1.19	279	385
Mississippi	276.9	1.32	309	427
Tennessee	260.2	1.27	297	411
Arkansas	291.3	1.38	325	447
Louisiana	2,202.7	8.73	2,043	2,825
Oklahoma	722.9	2.90	679	938
Texas	4,912.5	19.71	4,612	6,378
Arizona	192.5	1.04	243	337
Colorado	319.3	1.42	332	460
Idaho	53.1	.27	63	87
Montana	80.8	.38	89	123
Nevada	63.4	.32	75	104
New Mexico	312.4	1.32	309	427
Utah	124.9	.64	143	197
Wyoming	109.8	.54	126	175
California	1,851.6	9.82	2,298	3,178
Oregon	98.0	.51	119	259
Washington	182.7	.80	187	259

[a]in billions of cubic feet