

A Model for ASSESSING MINERAL RESOURCE ADVANTAGE

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A Model for Assessing Mineral Resource Advantage

by

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ABSTRACT

Kansas has a variety of mineral resources adaptable for a variety of uses. It is reasonable to speculate that mineral resource-related commodities could be produced in Kansas with a definite cost advantage over the same products produced in other states.

Utilizing an industrial-complex approach, this re-

port describes and applies a method for determining the extent of comparative regional advantage. The method is illustrated by analyses of hypothetical limestone, gypsum, and petrochemical complexes in Kansas. An input-output framework is used for computational purposes.

INTRODUCTION

At one time, Kansas oil, gas, lead, and zinc created significant mineral resource advantages for Kansas, but other states have since surpassed Kansas in the production of these commodities.

For the most part, Kansas mineral resources are not greatly different from those of surrounding states. It is entirely reasonable to speculate that processing of Kansas minerals into new materials would result in a cost advantage over similar products produced or shipped into the region to satisfy demand. Such activity is a form of regional specialization—the ability or endowments enabling one region to produce a commodity more efficiently than another region. The development of a refractory industry in Missouri is a prime example of regional specialization due to factor endowments.

The ability or endowments that result in a favorable cost differentiation for a region's commodities is a comparative advantage. An analytical method to measure comparative advantage is the theme of this report and the main purpose is to illustrate basic procedure. Data have been gathered from trade literature and textbooks. Results represent orders of magnitude rather than precise data for various commodities.

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REGIONAL ADVANTAGE

Regional advantage is a direct result of differences in resource endowments resulting in favorable cost differentials. Comparative regional advantage be-

comes effective under certain circumstances such as regional specialization, the result of an ability to produce a commodity more efficiently than any other region.

Kansas contains a variety of minerals that are also common to the neighboring states of Nebraska, Iowa, Missouri, Oklahoma, Colorado, and Wyoming. These minerals could be used as raw material for chemical or manufacturing complexes producing more than one product. Logically, industry selects locations that maximize returns on mineral-processing investments. A Kansas regional advantage would result from any combination of circumstances enabling the capital supplier to earn a higher return in Kansas than would be realized by locating in the regions surrounding Kansas.

INDUSTRIAL-COMPLEX APPROACH

In the mineral industries, two overriding considerations for processing are availability of raw materials and transportation costs associated with high-bulk, low-value materials. An industrial-complex approach is compatible with these factors and is the focus of this study. An industrial complex has been defined as a set of activities occurring at a given location and belonging to a group of activities which are subject to important production, marketing, or other interrelations (Isard, 1960). A complex can be located directly at the source of raw materials and gain many benefits from the operation of processes that are either complementary or that produce materials used as raw materials in other portions of the complex.

For example, limestone could provide the basis of an industrial complex in Kansas. Currently, the principal uses of limestone in Kansas are for portland

cement, road metal, concrete aggregate, and agricultural lime; however, many products depend upon limestone as the basic mineral (Fig. 1). It is reasonable to speculate that products could be produced from Kansas limestone resulting in a regional cost advantage for the State.

In this study an input-output framework is used for computational purposes and for analysis of the complex, the activities and inputs of the complex, and the relative advantage of its location in Kansas as compared to any of the six surrounding states: Missouri, Iowa, Nebraska, Colorado, Oklahoma, and Wyoming.

ANALYSIS OF REGIONAL MINERAL ADVANTAGE

The basic steps in performing a regional mineral advantage analysis (in this case, for Kansas) are as follows:

1. Choose any mineral for study.
2. Research the literature for product possibilities and select products on the basis of:
 - a. Market demand (annual)
 - b. Growth potential over a 20-year period
 - c. Technology required
3. Locate an industrial complex based on mineral deposits and potential major sources of product demand (large cities).
4. Based on product selections (which will be outputs for the complex), derive a market area using the following general techniques:
 - a. Locate plants in competing states which produce the same or similar products.
 - b. Draw straight lines from the Kansas complex to competing plants.
 - c. Bisect the straight lines and connect points surrounding the Kansas complex.
 - d. Derive a rough approximation of population for the enclosed area.
 - e. Multiply the ratio of market-area population to national population by aggregate demand for each product. This gives a *rough* approximation of the percent of total demand that the market area could expect.
5. Derive a production coefficient matrix for the selected products (outputs) by determining the physical quantities of the significant inputs (both direct and indirect) required to produce one unit of each

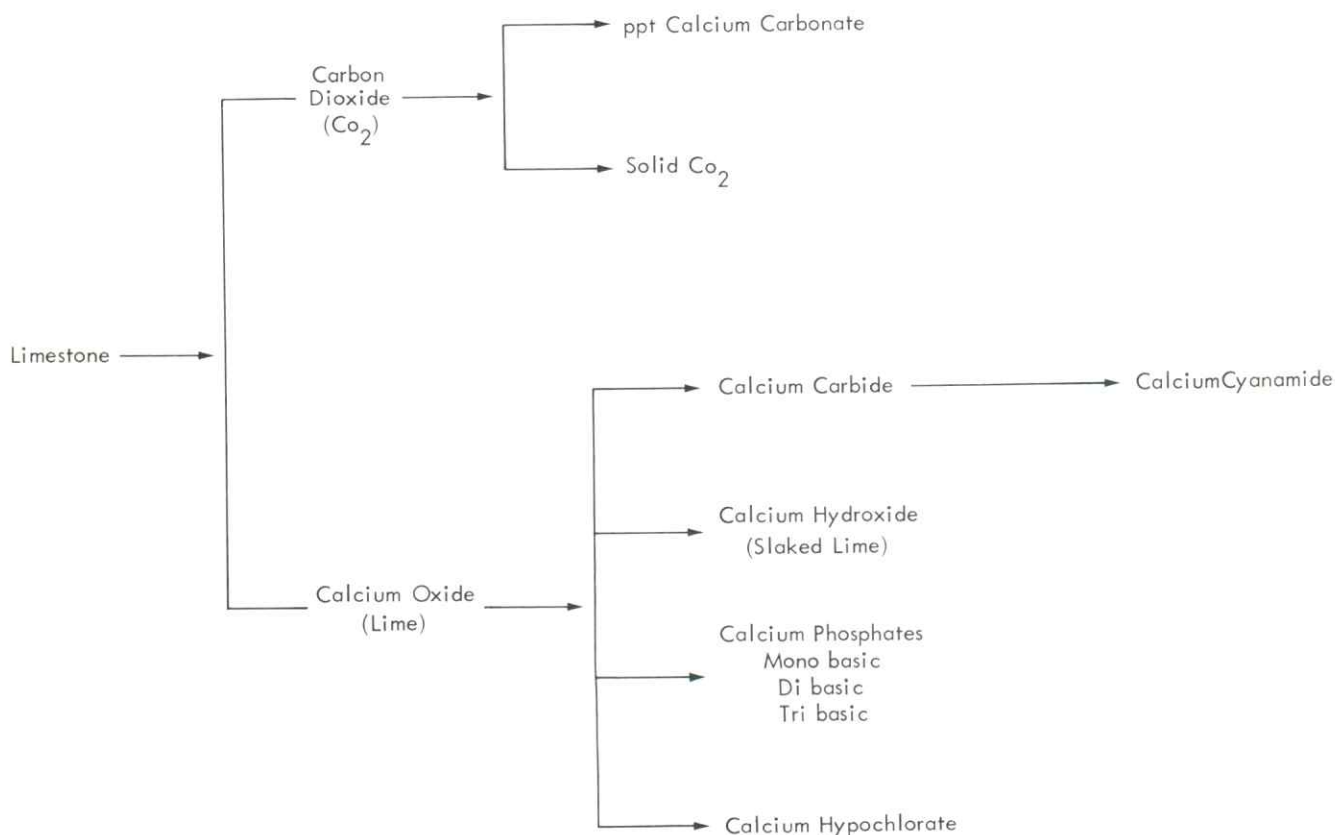


FIGURE 1.—Potential large-production-tonnage products from limestone. Each product in turn may be reacted with selected chemicals to produce numerous other calcium-containing compounds.

- output. This matrix will take the form of m rows (inputs) and n columns (outputs).
6. Derive an input cost differential matrix representing the difference in unit costs of the significant inputs between Kansas and all competing states. This matrix will take the form of k rows (competing states) and m columns (inputs).
 7. Input the data from 5 and 6 into a computer program for the purpose of performing the following computation:
 - a. Calculate the cumulative production coefficient matrix.
 - b. Multiply each row of the input cost differential matrix by the cumulative production coefficient matrix to derive k matrices, each of which will represent the output unit cost differentials between Kansas and one of the competing states.
 8. Complete the analysis using computer output.

Proceeding as outlined above, complexes dependent upon limestone, gypsum, and petrochemicals (coal-salt-natural gas) have been analyzed. Market demand is assumed to be sufficient to allow operation of the most efficient scale plant; all production data have been obtained under this assumption. At the present time, justification for this assumption of scale is merely subjective.

Cost relationships are assumed to vary linearly with output volume. Obviously, linearity is more applicable to some factors of production (such as raw materials) than to others (such as utility inputs), but within a limited range of volume, a linear approximation is not objectionable.

Transportation cost is initially assumed to be uniform throughout the region and vary linearly with distance from point of processing.

LIMESTONE COMPLEX

Products

Excluding cement, there are two basic forms of limestone (CaCO_3) products: calcined and uncalcined. It is not meaningful to apply the industrial-complex framework to uncalcined products such as crushed stone, dimension stone, and agricultural lime. With the exception of dimension stone, these products have low value per unit weight, thus their market value is closely tied to the cost of transportation. Calcined products, on the other hand, increase in value per unit weight with each process they undergo, and thus can reach markets at a greater distance from the place of manufacture.

The complex under consideration is one that produces lime (CaO), hydrated lime (Ca(OH)_2), calcium

carbide (CaC_2), and calcium cyanamide (CaCN_2). Limestone (CaCO_3) is used to produce lime (CaO), which in turn is used as an intermediate in the remaining processes and as a finished product.

Lime is widely used in water and waste treatment, metallurgical processes, manufacture of consumer products, and industrial construction. Overall continued growth of the lime market is anticipated.

Calcium carbide, manufactured by electrical resistance heating of lime and coke, is the intermediate compound from which is manufactured acetylene and calcium cyanamide. Acetylene is used in welding and as a raw material in plastics manufacturing.

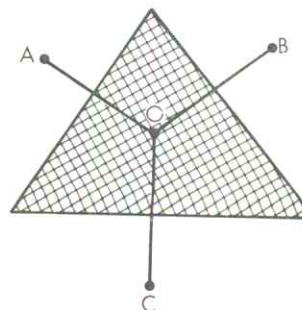
Calcium cyanamide is used as a speciality fertilizer, herbicide, defoliant, and as a raw material for manufacture of plastic. Many other compounds (Fig. 2) can be formed (Kastens and McBurney, 1953).

Since diversity of application is said to be the key to vitality in a chemical product, calcium cyanamide can be said to show good vitality. Much will depend on the ultimate economics of production of hydrogen cyanamide from calcium cyanamide. If this process can maintain its economic position, calcium cyanamide will feel the surge of acrylonitrile consumption that is now beginning.

Market Estimations

Location of the limestone complex is assumed to be at the geographical center of the high-quality (CaCO_3 content greater than 95 percent) limestone deposits in the east-central portion of Kansas. In order to obtain a rough idea of markets for the products listed, an area approximately 300 miles wide and completely surrounding Kansas was polled for present facilities with which the proposed complex would compete. Assuming that all plants are equally competitive and that transportation costs are uniform over the entire region, an area of market superiority may be determined by the following procedure (Woodard, 1967).

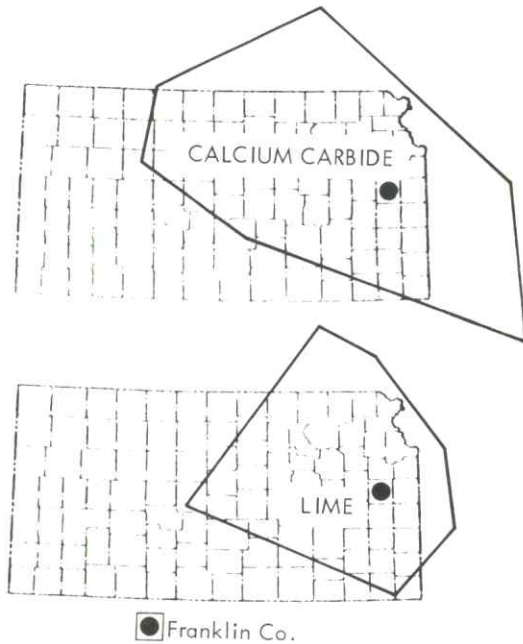
Let A, B, and C be plants with which the complex, O, must compete. Connect O with each plant by a straight line and then bisect each straight line with



a perpendicular line, extending the lines until a triangular area is created as shown. The area need not be triangular.

The crosshatched area then becomes an area of advantage to complex O simply due to the cost of transportation.

This procedure was used to determine market boundaries for calcium carbide and lime.



The calculated areas and related 1967 populations are:

	Area	Population
Calcium Carbide	73,137 sq. mi.	3,016,161
Lime	42,315 sq. mi.	2,447,467

No market boundaries are given for calcium cyanamide as it is not produced in the United States. Almost all calcium cyanamide is imported from Canada, where low-cost electric power attracts plants requiring large quantities of electricity to produce calcium carbide. In order to have a market figure it is arbitrarily assumed that approximately one-third of the total market could be captured by a Kansas complex.

For expedience and simplicity, per capita production of products was used as a criterion for market distribution. Table 1 presents the average markets

TABLE 1.—Estimated market distribution of calcium products manufactured in Kansas.

Product	Kansas market as percent of national market	Market (tons/year)
Lime (CaO)	1.23	162,298
Hydrated lime (Ca(OH) ₂)	1.23	32,298
Calcium carbide (CaC ₂)	1.52	13,667
Calcium cyanamide (CaCN ₂)	33.0	6,240

Source: Stanford Research Institute

that could be expected for a Kansas limestone complex.

The production and price history for the compounds are presented in Figures 3 and 4.

Production Coefficients

Primary and intermediate inputs for the complex had to be identified; primary inputs are limestone, coal, coke, electric power, and direct labor. Intermediate inputs of lime, hydrated lime, and calcium carbide were added.

Outputs are lime, hydrated lime, calcium carbide, and calcium cyanamide. Production of lime, hydrated lime, and calcium carbide are listed separately as both finished products and intermediates.

After determining location for the complex, products, and size of markets, the production coefficient matrix (Table 2) was set up. Values were calculated from basic chemical reactions and manufacturing energy requirements (Walker, *et al.*, 1937; Faith, *et al.*, 1957; Chilton, 1960).

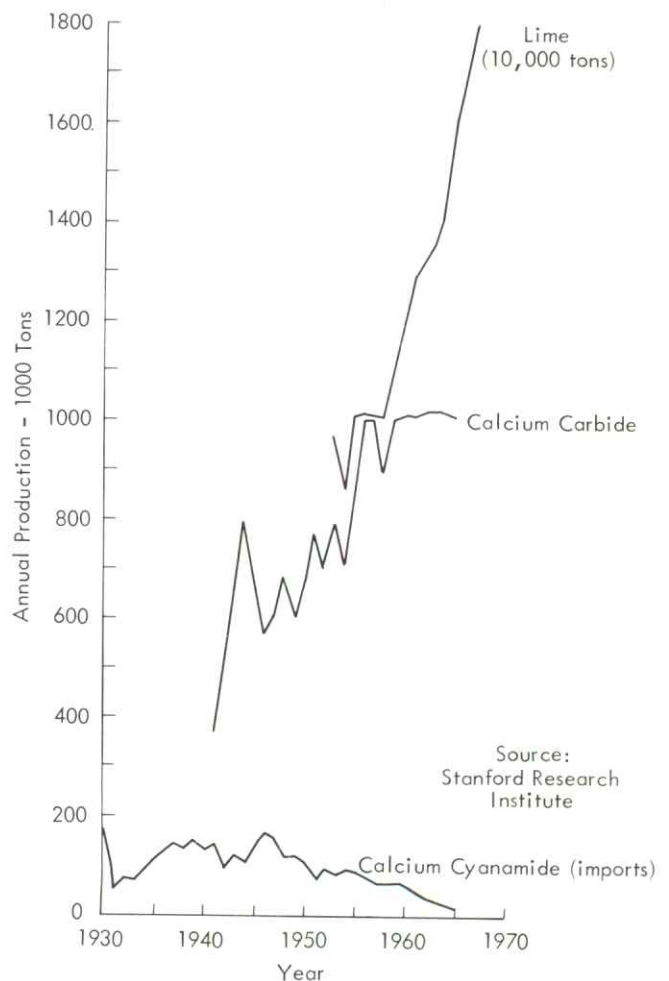


FIGURE 3.—U.S. production history of some calcium compounds.

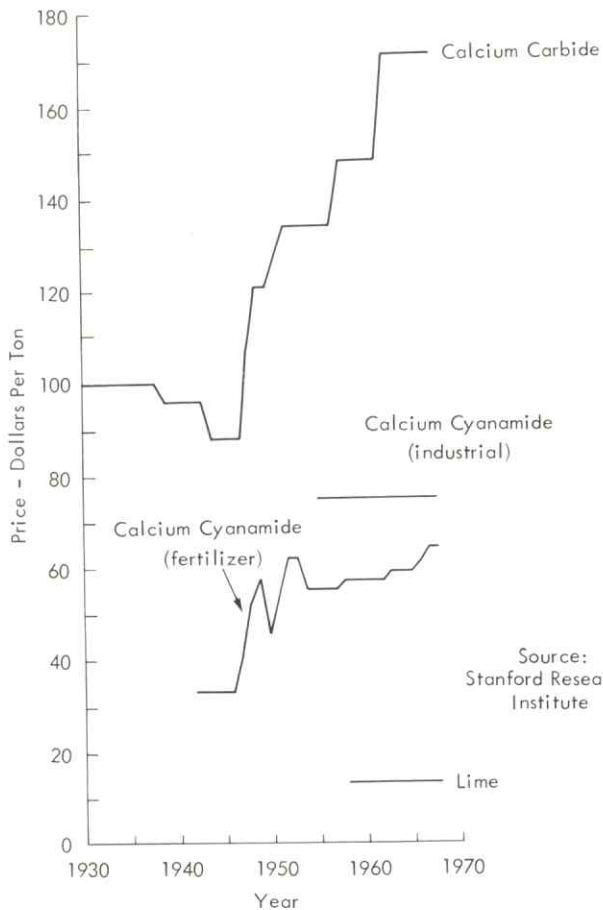


FIGURE 4.—U.S. price history of some calcium compounds.

TABLE 2.—Basic production coefficients of limestone complex requirements to produce 1 ton of CaO, Ca(OH)₂, CaC₂ and CaCN₂.

Input	Output			
	Lime (CaO)	Hydrated lime (Ca(OH) ₂)	Calcium carbide (CaC ₂)	Calcium cyanamide (CaCN ₂)
Limestone (tons)	1.88	.....	.....	.....
Lime (tons) .....	.....	0.76	0.95	.....
Calcium carbide (tons) ..	.....	.....	.....	0.94
Coal (tons)	0.297	.....	0.09	.....
Coke (tons) .....	.....	.....	0.65	.....
Electric power (1000 kw hrs)	0.1	0.02	3.0	0.58
Labor (man hrs)	1.56	0.5	3.0	0.516

Theoretically, pure limestone (CaCO₃) is 56 percent lime (CaO). One ton of CaO would require 1.78 tons of limestone, but the production coefficient is listed as 1.88. A figure larger than the theoretical tonnage appears because the limestone was assumed to contain 95 percent CaCO₃. Electric power and labor requirements are best estimates from literature sources.

The production coefficient matrix (Table 2) was next modified to show the cumulative summation of

primary raw material or intermediate product inputs needed to produce 1 ton of output product (Table 3).

TABLE 3.—Cumulative production coefficient matrix of limestone complex to produce 1 ton of CaO, Ca(OH)₂, CaC₂ and CaCN₂.

Input	Output			
	Lime (CaO)	Hydrated lime (Ca(OH) ₂)	Calcium carbide (CaC ₂)	Calcium cyanamide (CaCN ₂)
Lime [int.]° (tons)	0.	0.76	0.95	0.893
Calcium carbide [int.]° (tons)	0.	0.	0.	0.94
Limestone (tons)	1.88	1.429	1.786	1.679
Coal (tons)	0.297	0.226	0.372	0.35
Coke (tons)	0.	0.	0.65	0.611
Electric power (1000 kw hrs)	0.1	0.096	3.095	3.489
Labor (man hrs)	1.56	1.686	4.482	4.729

° Intermediate product

An example of how the production coefficients were calculated for Table 3 is shown by the production of 1 short ton of calcium carbide. From Table 2 we found that 1 ton of calcium carbide requires 0.95 ton of lime; but, to produce the lime we used limestone, coal, electric power, and labor. The inputs for the intermediate product lime must be accumulated into the production coefficient for calcium carbide.

The cumulative production coefficients were calculated using the following method:

Input	Lime (Intermediate product)	Calcium carbide (Final product)	Cumulative production coefficients for calcium carbide°
Limestone (tons)	(1.88) (.95)	+	0.0
Coal (tons)	(.297) (.95)	+	0.09
Coke (tons)	(0.0) (.95)	+	0.65
Electric power (1000 kw hrs) ..	(0.1) (.95)	+	3.9
Labor (man hrs)	(1.56) (.95)	+	3.0

° See Table 3, column 4.

Calculation of Regional Advantage

Calculation of regional advantage entails comparison of the operation of the complex at its assumed location in Kansas with alternative locations in the six surrounding states. Data on costs of inputs in Kansas and in the other states involved in this study are summarized in Table 4. Positive entries in the table indicate Kansas costs are lower—an advantage. For example, in the Missouri column, the entry of \$2.70 indicates that Kansas electric power is \$2.70 less per 1000 kw hrs than Missouri power. Negative entries indicate Kansas costs are higher. Basic cost data are listed in the Appendix.

TABLE 4.—Unit cost differentials of inputs, Kansas and surrounding states.

Input	Unit	Co'o-rado	Iowa	Mis-souri	Ne-braska	Okla-homa	Wyo-ming
Lime-stone	1 ton	\$1.23	\$0.36	\$0.06	\$0.92	\$0.13	\$0.50
Coal	1 ton	0.46	1.10	-0.49	-0.27	1.03	-1.53
Coke	1 ton	0.66	-1.29	-0.70	-0.39	1.47	-2.19
Electric power	1000 kw hrs	1.80	-0.90	2.70	-1.20	-1.70	0.90
Labor	man hrs	-0.14	-0.11	0.13	-0.79	0.33	0.56

Source: *Chemical Week*, 1968.

Results

Given the cost differential data and the data from the production coefficient matrix, the relative advantage of a Kansas complex per ton of output was calculated by multiplying the cumulative production matrix (Table 3) by the cost differential matrix (Table 4). The resulting information is summarized in Table 5. Again, positive entries indicate a Kansas cost advantage, negative entries indicate a disadvantage.

TABLE 5.—Relative advantage, Kansas vs. surrounding states, per ton of output (in dollars).

	Lime (CaO)	Hydrated lime (Ca(OH) ₂)	Calcium carbide (CaC ₂)	Calcium cyanamide (CaCN ₂)
Colorado	2.411	1.798	7.741	8.248
Iowa	0.148	0.39	-3.809	-4.159
Missouri	0.44	0.453	8.409	9.438
Nebraska	0.297	-0.193	-5.966	-6.711
Oklahoma	0.895	0.811	-2.211	-2.984
Wyoming	1.381	1.299	4.07	4.637

Nebraska has a cost advantage on all inputs except limestone (Table 4) and consequently has an output cost advantage on all outputs except lime (CaO). Missouri has a cost advantage on only two inputs, coal and coke, and as a result has an output cost disadvantage on all products with respect to Kansas. Similarly, Kansas has an advantage over Colorado on all products, while being at a disadvantage with respect to most Iowa products.

When the assumed location of the proposed limestone complex in Kansas is considered along with the foregoing cost analysis, it seems that the ideal marketing area for the output of the complex would be eastern Kansas and western Missouri, all other factors being equal. Of course, transportation-to-market costs may prove to be an equalizing factor in some or all of the above cases.

GYPSUM COMPLEX

Products

The mineral gypsum (CaSO₄·2H₂O) is deposited abundantly in a number of states. Plaster of paris is perhaps the most common name for processed gypsum.

Gypsum products can be classified into four basic categories: (1) uncalcined products; and those products requiring raw gypsum to be calcined or "boiled" before final preparation can be accomplished, (2) industrial plasters, (3) building plasters, and (4) pre-fabricated products.

Two of the most significant uses of uncalcined gypsum are as a soil additive in agriculture and as a set retarder in production of portland cement. Agricultural gypsum, commonly known as land plaster, is applied to sulfate-deficient soil and is used as a conditioner for highly alkaline soils. Uncalcined gypsum (3 to 6 percent by weight) is added to portland cement during the clinker grinding process to retard the setting (hardening) rate.

Uncalcined gypsum products are characteristically low in per-unit value, hence transportation cost normally limits the marketing of these products.

Industrial plasters find extensive use in construction products, molds, model building, and medical applications.

Historical U.S. production figures and price history for gypsum products are presented in Figures 5 and 6 (source: Standard Research Institute).

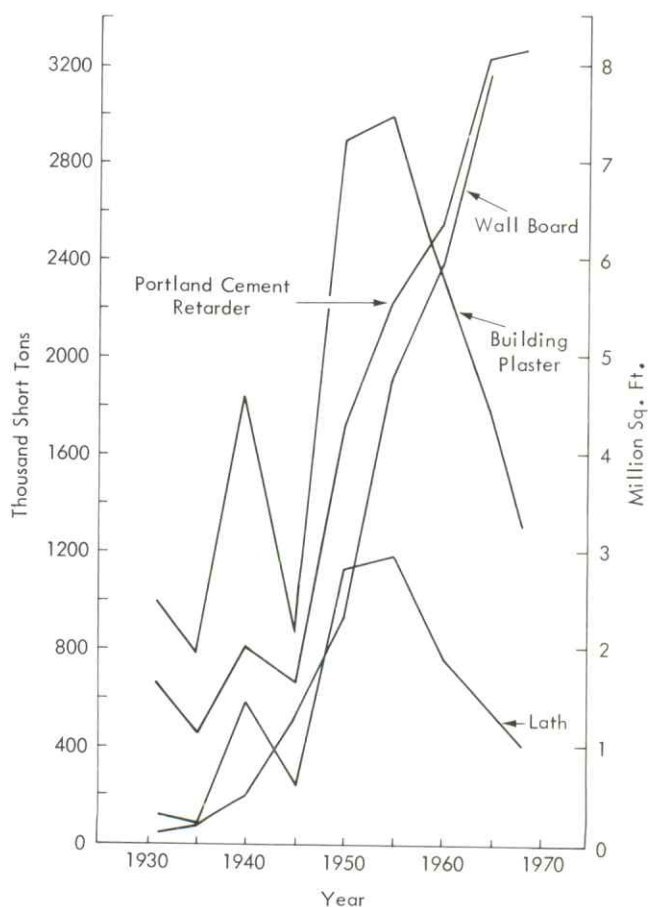


FIGURE 5.—U.S. production history of gypsum products.

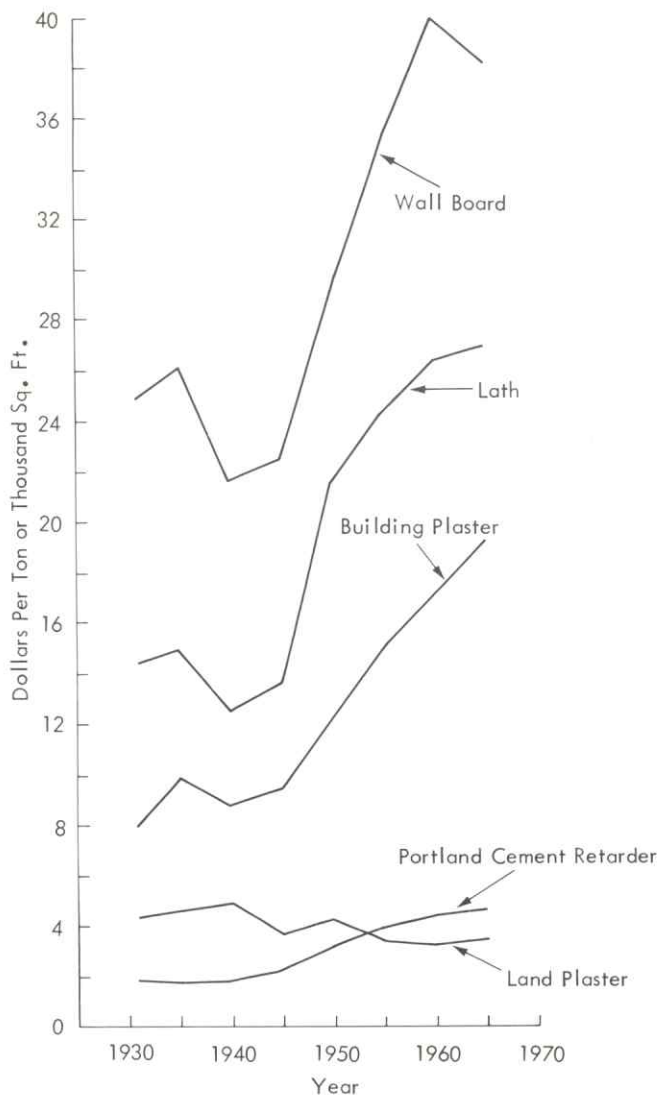


FIGURE 6.—U.S. price history of gypsum products.

Gypsum production has been and will continue to be highly dependent upon trends in population growth and housing demand. According to estimates (Bureau of Mines, 1965), domestic consumption of gypsum products will exceed 20 million tons by 1975, compared to a 1965 consumption of approximately 15 million tons.

The hypothetical gypsum complex proposed in this study is located in Saline County. The complex is considered to be capable of producing all of the products included in the gypsum input-output matrix (Table 6, p. 10).

An area of market superiority for this complex was derived by the procedure described previously. In this case, only one market area was derived for all products since most modern gypsum processing plants produce a full variety of products.

Market Estimations

Figure 7 depicts the market area of a proposed gypsum complex geographically located in the center of Kansas. It includes the entire State of Kansas and portions of Missouri and Nebraska. Note there are no gypsum mines in Missouri and Nebraska, but there are two operating in Kansas within the proposed region.

The market area includes approximately 119,000 square miles and a population of nearly 4 million people. As in the preceding section, a market estimate based on the ratio of the market-area population to national population would give a rough idea of the aggregate demand for the output of the proposed complex. On this basis, the market estimates below represent 2 percent of the aggregate U.S. consumption of gypsum products in 1968.

Land plaster	24,200 short tons/year
Portland cement retarder	72,400 short tons/year
Building plasters	26,200 short tons/year
Lath	21,000 short tons/year
	(or, 19,900,000 square feet/year)
Wallboard	170,000 short tons/year
	(or, 162,500,000 square feet/year)

Production Coefficients

Gypsum products considered in this analysis were gypsum wallboard and lath; base-coat, sanded, and pre-mixed perlite building plasters; and uncalcined products including portland cement retarder and land plaster (agricultural gypsum). These products were selected on the basis of their proportion of the total value of gypsum products produced in the United States in 1968. Industrial products were not included because of their relatively low proportional value. Production coefficients for each of these products were derived on the assumption that raw gypsum had been mined and was available for processing.

Production of portland cement retarder is essentially a one-stage process in which raw gypsum is ground to the desired size and screened out for sale to cement producers. Agricultural gypsum is produced in a two-stage process which includes grinding and milling raw gypsum to the desired size for application to the soil. Significant inputs to each process were considered to be gypsum, electric power, and labor.

Calcined gypsum is an intermediate product and for this reason its production was treated as a separate process. Calcination is a three-stage process in which the raw gypsum is ground, milled, and then "boiled" to produce hemihydrate (first-settle plaster). On the assumption that it was "boiled" in a gas-fired kettle, significant inputs to this process were considered to be

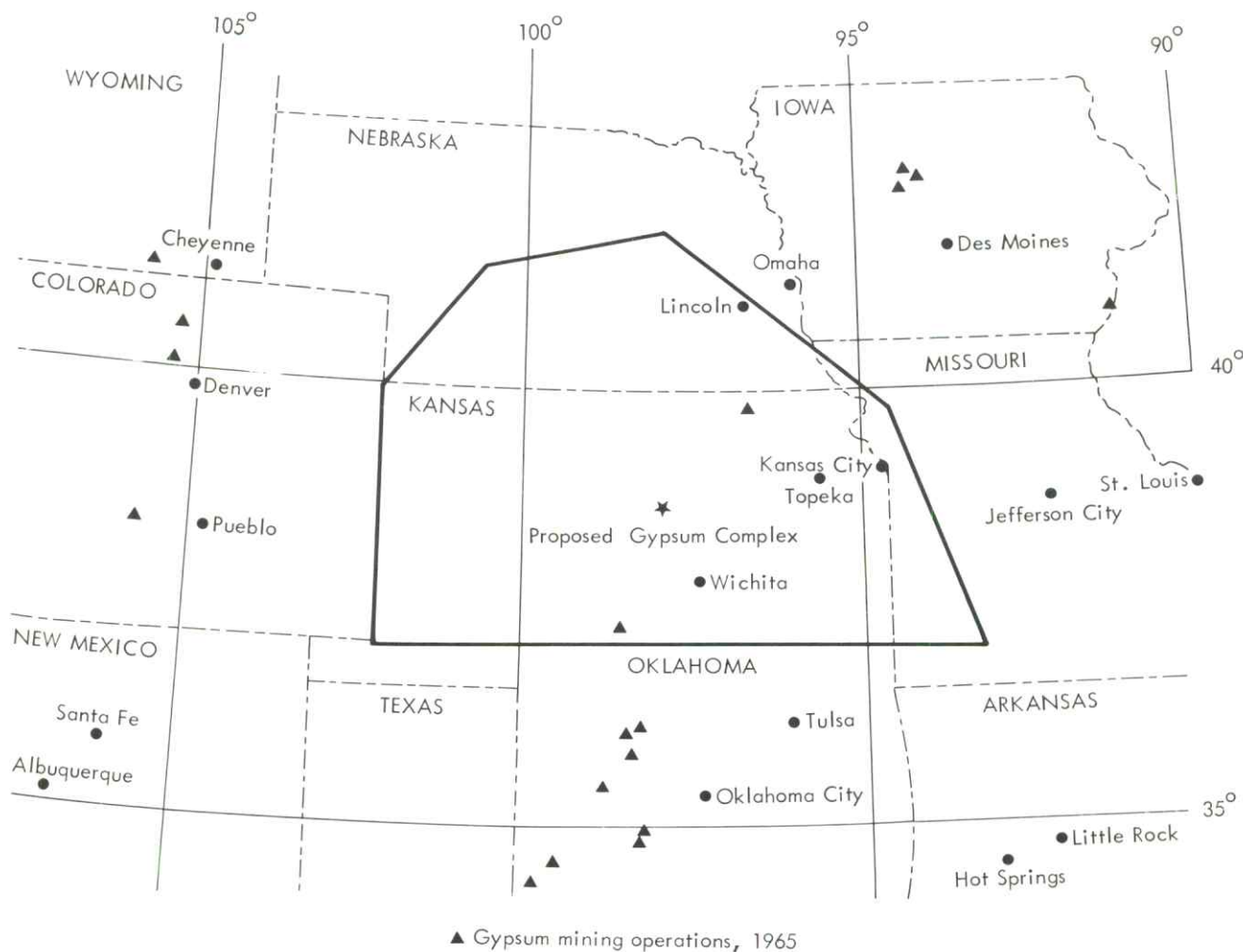


FIGURE 7.—Location of gypsum complex in Kansas. Market area enclosed by heavy dark lines.

gypsum, electric power, natural gas, and labor. Calcined gypsum is required in the production of building plasters, wallboard, and lath.

Building plasters are produced by milling calcined gypsum and then mixing it with various ingredients to give the plaster the desired characteristics. Significant inputs to this process are calcined gypsum, electric power, and labor.

Gypsum wallboard production is a highly automated process requiring calcined gypsum as the main input. The calcined gypsum is first mixed with water and other ingredients to form a slurry. The board machine sandwiches gypsum slurry between two layers of chip-board or paper, compressing it to the desired thickness. The formed board is then sent through a steam tunnel dryer to remove excess water from the gypsum core. The output of the dryer is the finished product. Assuming that steam for the dryer was generated by a gas-fired boiler, significant inputs to this process were considered to be calcined gypsum, electric power, natural gas, and labor. Production coefficients

for wallboard were derived on the basis of a ½-inch board thickness.

Lath production, although similar to that of wallboard production, requires more gypsum per 1000 square feet, so lath production was treated as a separate process. The production coefficients were derived for a lath thickness of one-half inch.

Production requirements for gypsum products are summarized in Table 6.

TABLE 6.—Basic production coefficients of gypsum complex requirements for 1 ton or 1000 square feet of ½-inch material.

Input	Output					Calcined gypsum (1 ton)
	Land plaster (1 ton)	Cement retarder (1 ton)	Building plaster (1 ton)	Wallboard (1000 sq. ft.)	Lath (1000 sq. ft.)	
Calcined gypsum (tons)	0.	0.	0.95	0.88	0.925	—1.0
Raw gypsum (tons)	1.0	1.0	0.	0.	0.	1.204
Electric power (1000 kw hrs)	0.005	0.003	0.015	0.025	0.026	0.01
Labor (man hrs)	0.3	0.3	0.3	0.67	0.67	0.2
Gas (1000 cu. ft.)	0.	0.	0.	2.45	2.45	1.17

In Table 7 are given cost differences of gypsum complex inputs between Kansas and the other six states. Positive entries represent a Kansas cost advantage; negative entries, a Kansas cost disadvantage.

TABLE 7.—Unit cost differentials of inputs, Kansas and surrounding states.

	Colo- rado	Iowa	Mis- souri	Ne- braska	Okla- homa	Wyo- ming
Gypsum (1 ton) ...	\$-0.15	\$0.60	—none mined—		\$-0.90	\$-0.20
Electric pow- er (1000 kw hrs) ..	1.80	-1.10	\$2.70	\$-1.20	-1.70	0.90
Labor (man hrs)	-0.14	-0.11	0.13	-0.79	0.33	0.56
Gas (1000 cu. ft.) ...	0.006	0.13	0.07	0.05	-0.03	-0.05

Results

After calculating the cumulative production coefficient matrix and multiplying this by the cost differential matrix, the cost difference per unit of output was derived (Table 8). Missouri and Nebraska are not represented because they do not mine gypsum.

TABLE 8.—Summary of cost differences per unit of output, Kansas vs. Colorado, Iowa, Oklahoma and Wyoming.

	Land plaster	Cement retarder	Building plaster	Wall- board	Lath
Colorado	\$-0.112	\$-0.166	\$-0.316	\$-0.108	\$-0.112
Iowa	-0.049	-0.022	0.088	0.559	0.562
Oklahoma	-0.837	-0.786	-1.705	-1.562	-1.596
Wyoming	0.134	0.107	1.037	-0.315	-0.319

Analysis of Table 7 reveals that a Kansas-based gypsum complex of the type proposed would have a significant input cost advantage over a similar complex based in Iowa and a significant disadvantage as compared to an Oklahoma-based complex. By analyzing Tables 7 and 8 it can be seen that these results are due mainly to the difference in gypsum cost between Kansas and the respective states.

Tables 7 and 8 indicate that the proposed Kansas complex would be more competitive with a similar complex located in Iowa, all other factors being equal and disregarding the Chicago marketing area. This is an ideal situation for the market area being considered (Fig. 7) which includes portions of Missouri and Nebraska that contain some of the more densely populated urban communities of these states. The market potential of the Kansas-based gypsum complex seems to be good with respect to building products in the northeastern Kansas-Missouri boundary region.

An Oklahoma-based complex would have a competitive edge over the Kansas-based complex. However, it is felt that this edge is not significant in an aggregate sense because of the market area under consideration. When distance to market and the ac-

companying transportation costs are considered, an Oklahoma-based complex would present the strongest competition in the southeastern portion of the market area. This portion includes only two major population centers, namely, Joplin and Springfield, Missouri. From the standpoint of aggregate market potential, this would not seem to significantly weaken the Kansas-based complex.

These results will undoubtedly be tempered one way or another when transportation costs, state taxes, and full operational costs are considered.

PETROCHEMICAL COMPLEX

There are three Kansas mineral resources which could become important raw materials in today's fast growing, versatile petrochemical industry: bituminous coal, salt (NaCl), and natural gas.

Although there are other states that have more abundant supplies of one or the other of these resources, Kansas is one of the relatively few states that has all three. In view of this fact and in view of the spectacular growth of the petrochemical industry over the past decade, it was decided to focus a part of this study on the output potentials for these resources on petrochemicals. A hypothetical petrochemical complex was constructed for utilizing coal, salt, and natural gas and their chemical derivatives. The complex is assumed to be located where the gathering cost of the raw materials is minimum.

Due to the relatively large number of output activities, no attempt has been made to define markets in terms of quantity demanded. Instead, manufacturing activities which should be sources of demand for potential products have been identified. These manufacturing activities, using petrochemicals as inputs, would be capable of producing a large variety of consumer products.

Selection of Output Activities

The method of selecting output activities for the hypothetical petrochemical complex was a three-step elimination process. First, an extensive review of various chemical products which could be derived from the three resources yielded a sizable list of basic chemical possibilities.

Secondly, the list of basic chemicals was searched for combinations which would yield further product possibilities. In this way, many of the basic chemicals were eliminated from further consideration; that is, those chemicals which could not be readily combined with others on the list were dropped.

Finally, product and market potential of the various chemical possibilities determined by the second

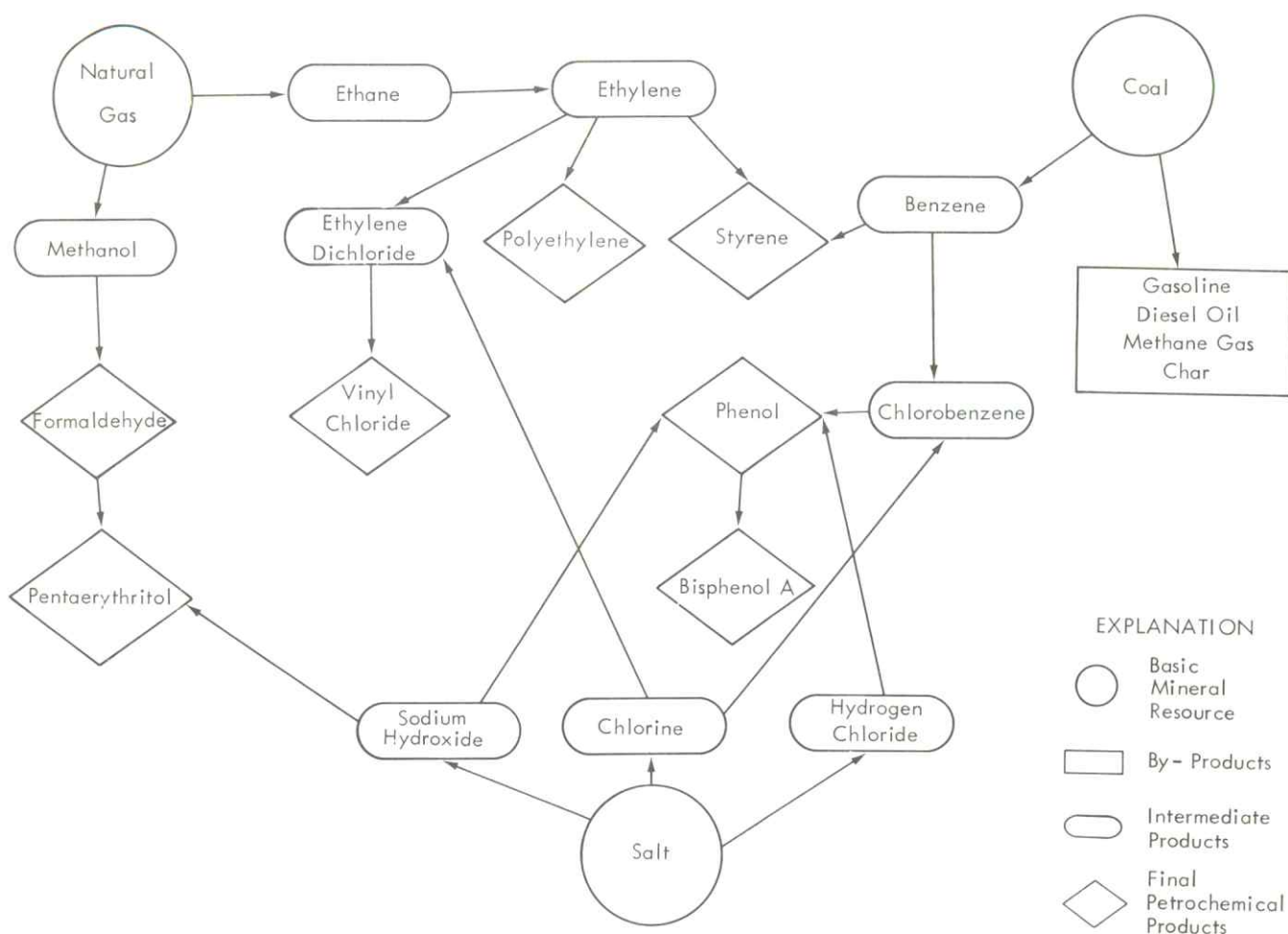


FIGURE 8.—Summary of petrochemical complex activities.

step were studied. Those chemicals that seemed to have most flexibility with respect to consumer products as well as those that seemed to have highest potential demand were retained; all others were eliminated.

Figure 8 summarizes the production activities and the products which comprise the petrochemical complex. Table 9 summarizes the major uses of the seven petrochemical products selected as output activities for the complex.

Production Coefficients

Only those inputs which were directly significant to production of individual products were considered. Because of the relatively large number of activities comprising the hypothetical petrochemical complex, it was necessary to segment the production process into five separate production matrices.

The first production matrix thus calculated concerns the intermediate products derived from basic salt (Tables 10 and 11). These intermediates—chlorine

TABLE 9.—Major uses of petrochemical products proposed to be manufactured from Kansas coal, salt, and natural gas.

Product	Polyethylene	Vinyl Chloride	Pentaerythritol	Phenol	Formaldehyde	Styrene	Bisphenol-A
	Film and sheet	Vinyl flooring	Surface coatings	Phenolic resins	Phenolic resins	Polystyrene plastics	Epoxy resins
	Injunction molding	Vinyl sheet	Adhesives	Caprolactom	Urea resins	Polyester resins	Polycarbonate resins
Uses	Blow molding	Adhesives	Flooring	Pesticides	Melamine resins	ABS resins	
	Paper coating	Wire coating	Lubricants	Alkylphenols	Ethylene glycol	Latexes	
	Wire coating	Film	Explosives	Medicinals	Polyacetal resins		
	Pipe and conduit	Records	Polyether plastics	Adipic acid			

TABLE 10.—Basic production coefficients for sodium hydroxide, chlorine, and hydrochloric acid from salt (to be used as intermediate products).

Input	Output	
	Sodium hydroxide [NaOH] 76% (1 ton)	Chlorine [Cl ₂] (tons/ton of NaOH, 76% output)
Salt [NaCl] (1.6 tons)	0.854	0.746
Electric power (1000 kw hrs)	1.6	1.4
Labor (man hrs)	9.0	9.0

Note: Chlorine and sodium hydroxide are produced simultaneously in the same electrolytic process.

TABLE 11.—Production coefficients to produce 1 ton of hydrochloric acid.

Input	Output
	Hydrochloric acid [HCl 20°B]
Chlorine [Cl ₂] (tons)	0.309
Hydrogen [H ₂] (tons)	0.011
Electric power (1000 kw hrs)	0.002
Labor (man hrs)	3.2

(Cl₂), caustic soda (sodium hydroxide, NaOH), and hydrochloric acid (hydrogen chloride, HCl)—are required in the production of other intermediates, which are, in turn, required in the production of final products. The inputs for this activities matrix are: salt, electric power, and labor. The production coefficients reflect the amount of input required per ton of output, unless otherwise specified. In this case, the input requirements are those of the electrolytic process for chlorine-caustic production (Shreve, 1967). The basic industrial input-output relationship between salt and chlorine (Shreve, 1967) is as follows:

	Yields	Fractional output
Salt 1.6 tons	76% NaOH 2000 lbs.	0.533
H ₂ SO ₄ 0.1 tons	Cl ₂ 1750 lbs.	0.467
Power 2.5 M kw hrs	3750 lbs.	
Labor 18 man hrs		

In order to eventually generate a cost for the NaOH and the Cl₂ the amount of salt and power was calculated on the basis of the proportion of NaOH and Cl₂ produced. Manpower was divided equally. The results of this manipulation are given in Table 10. Calculations were as follows: Value for NaOH, 76% = 1.6 tons (salt input) × (fractional output of 0.533) = 0.854 tons of salt input required for 1 ton of NaOH, 76% output. Chlorine value was arrived at by the same method. On a 1-ton basis of salt input, the fractional parts are equal to the output.

The second coefficient matrix calculated was that for coal and its intermediate product derivatives (Tables 12 and 13). In this case, coal, electric power, and labor were input to produce light oil, coke, and

TABLE 12.—Basic production coefficients for products from coal (to be used as intermediate products). Based on production of 1 gallon of light oil.

Input	Output		
	Light Oil (1 gallon)	Coke (tons)	Gas (1000 cu. ft.)
Coal (tons)	0.251	0.175	2.982
Electric power (1000 kw hrs)	0.023	-----	-----
Labor (man hrs)	0.386	-----	-----

TABLE 13.—Production coefficients required to produce 1 ton of benzene.

Input	Output
	Benzene
Light oil (gallons)	475.0
Electric power (1000 kw hrs)	0.1
Labor (man hrs)	0.5

coal gas. The light oil was then input, together with electric power and labor, to produce benzene, which is the only coal intermediate relevant to the petrochemical complex. The coal gas can be used as a fuel or sold to the public for consumption. The coke, along with more coal, can be used to produce liquid fuels such as gasoline and diesel oil. The production coefficients for this latter process are not given but the technical literature contains such information (*Hydrocarbon Processing*, Sept. 1969).

The third production matrix that was computed pertained to natural gas-derived intermediates—ethane and methanol (Table 14). These natural gas products are, by far, the most important to the potential outputs of the petrochemical complex. Five of the seven petrochemical outputs (Fig. 8) are basically derived from natural gas intermediates. Ethane is used to produce ethylene which is then used to produce polyethylene, styrene, and vinyl chloride. Methanol is used to produce formaldehyde which is then used to produce pentaerythritol.

TABLE 14.—Basic production coefficients for products from natural gas (to be used as intermediate products).

Input	Output	
	Ethane (1 million cu. ft.)	Methanol (1 ton)
Natural gas (million cu. ft.)	40.0	0.05
Electric power (1000 kw hrs)	0.3	0.07
Labor (man hrs)	27.0	0.5

The fourth production matrix, Table 15, gives the requirements for a second order of intermediate products which also are used in manufacturing the final compounds.

The final step in determining the physical requirements of the petrochemical complex was to compute the production coefficients for the final products. These are presented in Table 16.

TABLE 15.—Basic production coefficients for second order of intermediate products.

Inputs	Outputs		
	Ethyl dichloride (1 ton)	Chlorobenzene (1 ton)	Ethylene (1 ton)
Ethylene (tons)	0.315	-----	-----
Chlorine (tons)	0.8	0.875	-----
Benzene (tons)	-----	0.95	-----
Ethane (million cu. ft.)	-----	-----	0.031
Electric power (1000 kw hrs)	0.1	0.05	0.22
Labor (man hrs)	1.0	1.0	4.1

The six intermediate products derived from the raw minerals are used as basic inputs to these final product activities, along with utilities and labor. These intermediates are used as direct inputs to the final output activities and as indirect inputs by way of three more second-level intermediate activities. The second-level intermediate activities produce ethylene, chlorobenzene, and ethylene dichloride, which are used directly in final output activities. The raw minerals are not used directly in final output activities.

Five out of nine petrochemical products depend upon two or more intermediate products. Three of these—styrene, phenol, and bisphenol-A—depend upon benzene which is produced from coal. Four petrochemicals—pentaerythritol, vinyl chloride, phenol, and bisphenol-A—depend upon the chemical derivatives of salt: chlorine, sodium hydroxide, and hydrogen chloride. Finally, three of five interdependent products—styrene, vinyl chloride, and pentaerythritol—require the derivatives of natural gas, ethane, and methanol. Formaldehyde and polyethylene are independent in that they require only methanol and ethane respectively.

Determination of Regional Production Cost Differentials

Here, as in the previous sections, the purpose of analysis was to derive production cost differentials for

the products of the Kansas-based complex with respect to similarly produced products in six neighboring states. That is, given the fact that we can produce petrochemical products in Kansas, what are the cost advantages and disadvantages that such products would have over identical products being produced in Colorado, Iowa, Missouri, Nebraska, Oklahoma, and Wyoming? The implicit assumption that must be made, of course, is that the production coefficients for the relevant products are constant over the seven-state region.

Cost differences of the basic inputs—salt, coal, natural gas, electric power, and labor—were obtained. Differences for the minerals were derived from published data on the value of mineral production in the separate states (Bureau of Mines, 1967). Using Kansas mineral value as a basis, cost differentials were derived for salt, coal, and natural gas.

Although the cost differences for labor and electric power had previously been calculated, it was necessary to derive another set of differences for the electrical input because the electrical power rates applicable to the limestone- and gypsum-complex analyses do not apply in the case of salt-derived products. Chlorine, caustic soda, and hydrogen chloride are produced from salt by the Downs cell electrolytic process which consumes large amounts of electric power. For this reason, a different rate schedule for calculating cost differences was used. In most cases, results were significantly different from costs derived previously.

Table 17 summarizes cost differences for the basic inputs discussed above. As before, negative figures represent cost disadvantages for the Kansas-based complex.

Cost differences presented in Table 17 were used to compute another set of cost differences associated with the intermediate product derivatives of salt, coal, and natural gas. Table 18 summarizes the cost differ-

TABLE 16.—Basic production coefficients for 1 ton of final products.

Inputs	Outputs									
	Bisphenol-A	Phenol	Formaldehyde	Polyethylene	Styrene	Vinyl chloride	Pentaerythritol	Ethyl dichloride	Chlorobenzene	Ethylene
Formaldehyde (tons)	-----	-----	1.0	-----	-----	-----	3.17	-----	-----	-----
Ethyl dichloride (tons)	-----	-----	-----	-----	-----	1.65	-----	-1.0	-----	-----
Chlorobenzene (tons)	-----	1.25	-----	-----	-----	-----	-----	-1.0	-----	-----
Ethylene (tons)	-----	-----	-----	1.09	0.32	-----	-----	0.315	-----	-1.0
Chlorine [Cl ₂] (tons)	-----	-----	-----	-----	-----	-----	-----	0.8	0.875	-----
Sodium hydroxide [NaOH] (tons)	-----	1.37	-----	-----	-----	-----	1.05	-----	-----	-----
Hydrochloric acid [HCl] (tons)	0.145	0.51	-----	-----	-----	-----	-----	-----	-----	-----
Benzene (tons)	-----	-----	-----	-----	0.865	-----	-----	-----	0.95	-----
Methanol (tons)	-----	-----	0.47	-----	-----	-----	-----	-----	-----	-----
Ethane (million cu. ft.)	-----	-----	-----	-----	-----	-----	-----	-----	-----	0.031
Electric power (1000 kw hrs)	0.13	0.05	0.07	0.5	0.5	0.05	0.1	0.1	0.05	0.22
Labor (man hrs)	2.5	1.0	0.5	2.0	2.0	0.5	0.5	1.0	1.0	4.1

TABLE 17.—Unit cost differentials of inputs, Kansas and surrounding states.

	Colorado	Iowa	Missouri	Nebraska	Oklahoma	Wyoming
Salt (1 ton)	\$ 5.40	\$ 5.40	\$ 5.20	\$ 5.40	\$ 4.60	\$ 6.60
Coal (1 ton)	0.46	-0.90	-0.49	-0.27	1.03	-1.53
Natural gas (1 million cu. ft.)	-5.00	65.00	30.00	24.00	5.00	10.00
Labor (man hrs)	-0.14	-0.11	0.13	-0.79	0.33	0.56
Electric power (1000 kw hrs)	2.50	5.20	-1.00	1.00	0.40	2.00
Electric power ^o (1000 kw hrs)	2.50	-0.90	2.70	1.00	-1.70	0.90

^o Large industrial power rates used in production of chlorine, sodium hydroxide, and hydrogen chloride by electrolysis of salt brine.

TABLE 18.—Cost differentials of intermediate products (\$/ton).

	Colorado	Iowa	Missouri	Nebraska	Oklahoma	Wyoming
Chlorine	\$ 5.69	\$ 1.99	\$ 8.21	\$-1.91	\$ 4.41	\$11.02
Sodium hydroxide	6.68	2.42	9.20	-1.17	4.64	11.87
Hydrogen chloride	1.32	0.26	2.96	-3.12	2.42	5.20
Benzene	56.67	-70.20	-45.54	-166.41	187.88	-57.41
Methanol	-0.14	3.56	1.49	0.87	0.44	0.92
Ethane	0.20	0.60	0.20	0.94	0.21	0.42
Ethane dichloride	2.67	27.60	18.45	6.00	6.39	14.50

TABLE 19.—Cost differentials of final products (\$/ton).

	Colorado	Iowa	Missouri	Nebraska	Oklahoma	Wyoming
Polyethylene	\$-5.92	\$ 90.94	\$ 40.76	\$ 27.36	\$ 9.49	\$ 19.15
Formaldehyde	0.04	1.98	0.70	0.08	0.40	0.85
Phenol	83.31	-77.40	-30.81	-204.56	-236.31	-35.72
Bisphenol-A	77.98	-71.85	-28.15	-193.36	221.94	-30.95
Styrene	47.97	-32.34	-28.60	136.68	165.91	-42.54
Vinyl chloride	4.46	45.74	30.45	9.56	10.73	24.30
Pentaerythritol	7.32	9.28	11.84	-1.27	6.34	15.64

entials for all seven intermediate products. This second set of cost differentials was then used to compute the final product cost differentials, summarized in Table 19. Prices shown are, for the most part, 1968 figures.

Economic Implications

If only cost differentials listed in Table 19 are considered, it can be concluded that Kansas is in a good competitive position with respect to polyethylene, formaldehyde, vinyl chloride, and pentaerythritol production. The other three products—phenol, bisphenol-A, and styrene—do not seem to offer much potential for profitable production in Kansas.

A natural question to ask at this point is: What are the determining factors of these results? This would be a difficult question to answer for any one particular cost differential; but, for a particular product or group of products, it is fairly easy to answer. In particular, consider the latter three products mentioned above.

Figure 8 shows that phenol and styrene both require benzene in the production process through the intermediate product, chlorobenzene, and in the latter case benzene enters directly into the process. Referring to Table 17, it can be seen that benzene has a

highly negative cost differential associated with it, as does chlorobenzene. The negative cost differentials for these products can be explained by considering the relatively large amounts of these intermediates needed in the production of styrene and phenol. Since bisphenol-A is a direct product of phenol, the sign of these cost differentials is also explained. But what about the intermediate cost differentials?

Since chlorobenzene is a product of benzene and chlorine, we need only consider the signs and relative magnitudes of the latter cost differentials. In most cases, the chlorine differentials are positive and small relative to those of benzene. It can be concluded that the benzene differentials are the determining factor in the case of chlorobenzene.

Finally, benzene itself is produced from light oil which is derived from coal. In Table 13, it can be seen that it takes 475 gallons of light oil to produce 1 ton of benzene. Furthermore, it takes about a quarter of a ton of coal to get 1 gallon of light oil (Table 12). It is clear that this production process requires a considerable amount of coal to get 1 ton of benzene output. Considering cost differentials associated with coal, although seemingly not critical at first glance, these differences are indeed the major determinant of

the final product cost differentials for phenol, bisphenol-A, and styrene.

Analysis of this type could be carried out as well for those products having favorable cost differentials. The results of such analysis would show that favorable differentials associated with natural gas are the major determinants for the favorable differentials of the final products.

It seems that within the seven-state region, a Kansas-based petrochemical complex would be more competitive with respect to products derived from natural gas and salt than those derived from coal. However, if production methods for coal could be improved so as to decrease the minehead value of coal, the competitive nature of coal-derived petrochemicals in Kansas would be considerably enhanced.

As a final comment, it should be noted that the cost differentials thus derived do not in themselves guarantee a competitive position for a Kansas-based petrochemical complex. There are many other questions still unanswered. For example: Does Kansas have a sufficient supply of basic inputs to enable such a complex to be operated at profitable production levels? What effect would transportation costs have on the market potential of the products? These are very important questions and must be answered before any conclusive statements can be made. But, in spite of these unanswered questions, this analysis sheds considerable light on the feasibility of producing petrochemicals in Kansas.

SUMMARY

A procedure has been demonstrated for comparing costs of products made in Kansas from Kansas minerals with costs of identical products made in states surrounding Kansas, in order to determine potential mineral resource advantage.

Basic cost data utilized in this study are from published literature and do not reflect actual current costs. For more precise studies refined and specific data would be required. Other costs factors may be introduced into the matrix. For accurate analysis, actual transportation costs should be included. An improved method of estimating consumption and marketing of final products is also needed.

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APPENDIX

BASIC COST DATA

Labor costs were obtained from trade literature (*Chemical Week*, October 5, 1968) and are as follows:

State	Average hourly earnings (June 1968)
Colorado	\$3.18
Iowa	3.21
Kansas	3.32
Missouri	3.45
Nebraska	2.53
Oklahoma	3.65
Wyoming	3.88

Fuel and power costs were obtained from the same source.

State	Average chemical industry power costs (¢/kw hr)	Industrial material gas (¢/Mcf)	Wellhead national gas prices (¢/Mcf)	Typical large industrial power rates (¢/kw hr)
Colorado	1.00	23.6	13.0	0.65
Iowa	0.73	35.8	20.0	0.92
Kansas	0.82	23.0	13.5	0.40
Missouri	1.09	30.3	16.5	0.30
Nebraska	0.70	28.2	15.9	0.50
Oklahoma	0.65	20.1	14.0	0.44
Wyoming	0.91	18.2	14.5	0.60

Prices of raw materials were generated from actual canvass of limestone and salt producers and from value figures for coal and gypsum as reported by the U.S. Bureau of Mines (1965).

Prices per ton, bulk, carload, at point of use.

State	Crushed limestone (1965)	Washed coal (1965)	Rock salt (1965)	Raw gypsum (1966)
Colorado	\$2.29	\$5.10	\$12.90	\$3.60
Iowa	1.42	3.54	12.90	4.35
Kansas	1.06	4.64	7.50	3.75
Missouri	1.00	4.15	12.70	-----
Nebraska	1.98	4.37	12.90	-----
Oklahoma	1.13	5.67	12.10	2.85
Wyoming	1.56	3.11	14.10	3.55

