Effects of Coal Blending on the Utilization of High-Sulfur Iowa Coal and Low-Sulfur Western Coal

John J. Miller, Thomas P. Drinka, Craig W. O'Riley, and C. Phillip Baumel

Sulfur dioxide emission standards for coal-fired stationary boilers generally range from 1.2 pounds per million Btu of heat input for large boilers constructed after August 17, 1971 to 5 to 6 pounds of SO_2 emissions for other large boilers constructed on or before August 17, 1971 and for boilers located in nonrural areas. These standards generally prohibit the use of coal with sulfur contents > 0.6 percent for new large boilers and > 2.5 to 3.0 percent in other boilers. Low-sulfur western coal shipped in unit-trains and mechanically blended with higher-sulfur coals located close to the boilers provides a method of increasing the production of the high-sulfur Iowa coal as well as the consumption of low-sulfur western coal and, at the same time, of reducing the total cost of the projected 1980 coal consumption in Iowa.

Iowa coal production declined from 1 million tons in 1971 to 540,000 tons in 1976. Only 259,000 tons of Iowa coal were strip mined in 1975 [U.S. Department of the Interior, 1971, 1976, 1977]. This decline is attributable to a number of factors. First, low-cost, 100-car unit trains hauling low-sulfur Western coal have recently become available in Iowa. Second, the small scale of Iowa mining operations and the relatively thin Iowa coal seams lying deep underground result in relatively high mining costs. Finally, imposition of sulfur dioxide emission standards has augmented the decline in Iowa coal production. The U.S. Environmental Protection Agency has adopted a national standard that restricts SO_2 emissions to 1.2-pounds per million Btu input at coal-fired stationary boilers with a heat input of greater than 250 million Btu per hour that are constructed after August 17, 1971, [U. S. Environmental Protection Agency]. State, county, or city standards for small boilers or boilers constructed before August 17, 1971, in Iowa are for 5-, 6-, or 8-pounds of SO_2 per million Btu of heat input, depending upon the boiler location [Linn County, Polk County Board of Health, State of Iowa]. Assuming coal with 10,000 Btu per pound, only coal with less than or equal to 0.6, 2.5, 3.0, or 4.0 percent sulfur, respectively, could be burned in these boilers under these standards. Strippable coal reserves in Iowa typically average between 3.1 and 5.8 percent sulfur [Avcin].

One method of improving the competitive position of high-sulfur coal is to reduce the sulfur content through coal beneficiation [Grieve and Fisher]. Coal beneficiation is a mechanical process in which crushed coal is passed through water, and sulfur is separated out by the difference in specific gravity between coal and sulfur. Another method may be to blend the high-sulfur coal with low-sulfur coal. Blending plants could be con-

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structed to receive two or more coals, store them separately, simultaneously reclaim the individual types separately, blend the coals to specific qualities, and load-out the various blends of coal. Blending precision could be obtained by including belt scales and samplers in the conveying systems.[1] If the competitive position of the Iowa coal industry can be improved by coal-blending, the optimal number and location of blending plants must be determined.

The purposes of this paper are to present estimates of the impact of blending high-sulfur Iowa coal with low-sulfur Wyoming coal on the competitive position of Iowa coal, and to compare the blending alternative with a coal-beneficiation alternative. The specific objectives of this study are to determine the optimal origin, mode of transport and amount of coal shipped to each major coal user in Iowa, the optimal number and location of coal-beneficiation plants, the optimal number and location of coal-blending plants under a coal-blending alternative, and the users who would expand coal receiving capacity under current sulfur emission standards, so as to minimize the total delivered cost of the projected 1980 coal consumption in Iowa and, finally, to compare the results of the coal-blending alternative with a coal-beneficiation alternative analyzed by Baumel, Drinka and Miller.

Method of Analysis

A mathematical mixed integer programming model is used to evaluate the feasibility of mechanically blending Iowa coal with out-of-state coals for use by Iowa coal users. The objective function of the model minimizes the cost of supplying Iowa users' 1980 coal consumption subject to constraints on mining capacity, beneficiation plant capacity, blending plant capacity, receiving capacity of users, sulfur dioxide emission standards, and projected 1980 coal consumption in Iowa. The model uses continuous variables for mining, beneficiation, blending, and transportation activities and zero-one integer variables for construction of beneficiation plants, construction of blending plants, and expansion of user rail-receiving capacities. The model is summarized as:

$$
\begin{aligned}
(1)\ & \text{minimize } Z \\
&= \sum_i P_i M_i + \sum_i \sum_k \sum_m a_{ikm} U_{ikm} + \Psi \sum_i \sum_j b_{ij} \left[\sum_k \sum_m V1_{ijkm} + \sum_n \sum_m V2_{ijnm} \right] \\
&+ (\Psi - 1) \sum_i \sum_j c_{ij} \left[\sum_k \sum_m Vi_{ijkm} + \sum_n \sum_m V2_{ijnm} \right] + \alpha \sum_i \sum_j \left[\sum_k \sum_m V1_{ijkm} \right. \\
&\left. + \sum_n \sum_m V2_{ijnm} \right] + \sum_i \sum_j \sum_k \sum_m d_{jkm} V1_{ijkm} + \sum_j FC_j Y_j + \sum_k EC_k X_k \\
&+ \sum_i \sum_n \sum_m e_{inm} L_{inm} + \sum_i \sum_j \sum_n \sum_m f_{jnm} V2_{ijnm} + \sum_n BFC_n W_n + \beta \left[\sum_i \sum_n \sum_m L_{inm} \right. \\
&\left. + \sum_i \sum_j \sum_n \sum_m V2_{ijnm} \right] + \sum_n \sum_k \sum_m \sum_q g_{nkm} R_{nkmq}
\end{aligned}
$$

where

Z = total cost,

P_i = price per unit of coal at mine i,

M_i = volume of coal supplied by mine i,

a_{ikm} = transportation plus variable re-

[1]The typical method currently used by Iowa utilities to blend Iowa coal with low-sulfur coal is to dump a front-end loader scoop of Iowa coal and then another scoop of low-sulfur coal into the reclaim hopper. In addition to being imprecise, this method creates variations in heat which cause boiler steam pressure to vary.

ceiving cost per unit of coal shipped from mine i to user k by mode m,

U_{ikm} = volume of coal shipped from mine i to user k by mode m,

Ψ = inverse of the fractional weight recovery at beneficiation plants,

b_{ij} = transportation cost per unit of coal shipped from mine i to beneficiation plant j,

c_{ij} = transportation cost per unit of refuse shipped from beneficiation plant j to mine i,

$V1_{ijkm}$ = volume of clean coal equivalent shipped from mine i through beneficiation plant j to user k by mode m,

$V2_{ijnm}$ = volume of clean coal equivalent shipped from mine i through beneficiation plant j to blender n by mode m,

α = variable beneficiation cost per unit of clean coal,

d_{jkm} = transportation and variable receiving cost per unit of clean coal shipped from beneficiation plant j to user k by mode m,

FC_j = annual fixed cost of establishing a beneficiation plant at site j,

Y_j = (0, 1), a binary variable; if beneficiation plant j is used, $Y_j = 1$, otherwise $Y_j = 0$,

EC_k = annual fixed cost of expanding the rail receiving capacity of user k to the next larger size,

X_k = (0, 1), a binary variable; if user k expands its rail receiving capacity, $X_k = 1$, otherwise $X_k = 0$,

e_{inm} = transportation and variable receiving cost per unit of coal shipped from mine i to blending plant n by mode m,

L_{inm} = volume of coal shipped from mine i to blending plant n by mode m,

f_{jnm} = transportation and variable receiving cost per unit of clean coal shipped from beneficiation plant j to blending plant n by mode m,

BFC_n = annual fixed cost of establishing a blending plant at site n,

W_n = (0, 1), a binary variable; if blending plant n is used, $W_n = 1$, otherwise $W_n = 0$,

β = variable blending cost per unit of coal,

g_{nkm} = transportation and variable receiving cost per unit of coal shipped from blending plant n to user k by mode m, and

R_{nkmq} = volume of coal of quality q shipped from blending plant n to user k by mode m.

A total of 33 potential coal mines are included to meet the projected 1980 consumption of 46 major coal users in Iowa. Users' consumption can be satisfied by receiving coal directly from any combination of Iowa underground mines, out-of-state mines, beneficiation plants or blending plants. Because of its high sulfur content, Iowa strip mine coal must either be beneficiated or blended.

The model includes barge, truck, single-car rail, 15-car rail, 50-car rail, and 100-car unit train as mine-to-user transportation modes. All 46 users can receive coal by truck. Eight users have barge receiving facilities, while the present number of coal users with rail receiving capacity of single-car, 15-car, 50-car, and 100-car unit train are 20, 16, 1, and 3, respectively. The possible transportation modes from blending plants and from beneficiation plants to users are truck, single-car rail, 15-car rail, and 50-car rail. Each user has the option of receiving the coal by the least costly mode, subject to the users' existing modal receiving capacity. A coal user incurs an additional annual fixed cost to expand its rail receiving capacity to the next larger shipment size. If the projected 1980 coal consumption would provide less than one shipment per month at the next larger shipment size or if the user historically received all of its coal by truck and (or) barge, the user was not given the opportunity to increase its rail receiving capacity.

The cost of blending coal includes the total annual fixed cost of a blending plant, the variable cost of operating the plant, the cost of transporting raw Iowa strip-mined coal and (or) beneficiated Iowa coal to a blending plant, and the cost of transporting out-of-state coal to a blending plant. The cost of beneficiating Iowa coal includes the total annual cost of constructing a plant, the variable operating cost, and the cost of transporting the raw coal from the mine to the beneficiation plant and the refuse from the beneficiation plant to the mine.

A number of constraints were imposed on the model. The annual volume of coal shipped from a mine cannot exceed the annual production capacity of that mine:

$$(2)\ \sum_{k}\sum_{m} U_{ikm} + \Psi\sum_{j}\sum_{k}\sum_{m} V1_{ijkm} + \Psi\sum_{j}\sum_{n}\sum_{m} V2_{ijnm} + \sum_{n}\sum_{m} L_{inm} = M_i \leq MC_i$$

where MC_i = total annual production capacity of mine i.

The annual volume of coal beneficiated at a plant cannot exceed the annual beneficiation plant capacity:

$$(3)\ \sum_{i}\sum_{k}\sum_{m} V1_{ijkm} + \sum_{i}\sum_{n}\sum_{m} V2_{ijnm} \leq BC_j$$

where BC_j = annual beneficiation plant capacity in units of clean coal at site j.

The demand for coal at each user must be satisfied. Demand is specified in heating value rather than tons to account for the difference in heating values of coal from the different mines:

$$(4)\ \sum_{i}\sum_{m} \lambda_i U_{ikm} + \sum_{i}\sum_{j}\sum_{m} \tau_i V1_{ijkm} + \sum_{n}\sum_{m}\sum_{q} \gamma_{kq} R_{nkmq} \geq D_k$$

where λ_i = heating value per unit of raw coal from mine i, τ_i = heating value per unit of clean coal from mine i, γ_{kq} = heating value per unit of blended coal of quality q for user k, and D_k = exogenously determined consumption at user k.

Each user is required to meet an aggregate limit on sulfur dioxide emissions:

$$(5)\ \sum_{i}\sum_{m} \sigma_i U_{ikm} + \sum_{i}\sum_{j}\sum_{m} \Theta_i V1_{ijkm} + \sum_{n}\sum_{m}\sum_{q} {}_{kq}R_{nkmq} \leq S_k = \pi_k D_k$$

where σ_i = units of sulfur dioxide contained in one unit of raw coal from mine i, Θ_i = units of sulfur dioxide contained in one unit of clean coal from mine i, ℓ_{kq} = units of sulfur dioxide contained in one unit of blended coal of quality q for user k, S_k = maximum allowable sulfur dioxide emissions at user k, and π_k = maximum allowable emission standard measured as units of sulfur dioxide per unit of heating value.

The annual volume of coal blended at a blending plant cannot exceed the annual plant capacity:

$$(6)\ \sum_{i}\sum_{j}\sum_{m} V2_{ijnm} + \sum_{i}\sum_{m} L_{inm} = \sum_{k}\sum_{m}\sum_{q} R_{nkmq} \leq BLC_n$$

where BLC_n = annual blending plant capacity at site n.

The equivalent number of heating value units shipped into a blending plant must equal or exceed the equivalent number of heating value units shipped out of a blending plant:

$$(7)\ \sum_{i}\sum_{j}\sum_{m} \tau_i V2_{ijnm} + \sum_{i}\sum_{m} \lambda_i L_{inm} \geq \sum_{k}\sum_{m}\sum_{q} \gamma_{kq} R_{nkmq}$$

The equivalent number of units of sulfur dioxide emissions shipped into a blending plant must be less than or equal to the equivalent number of units of sulfur dioxide emissions shipped out of the blending plant:

$$(8)\ \sum_i\sum_j\sum_m \Theta_i V2_{ijnm} + \sum_i\sum_m \sigma_i L_{inm} \leq \sum_k\sum_m\sum_q \ell_{kq} R_{nkmq}\,.$$

Additional nonnegativity constraints are:

$$(9)\ M_i,\ U_{ikm},\ V1_{ijkm},\ V2_{ijnm},\ Y_j,\ X_k,\ L_{inm},\ W_n,\ R_{nkmq} \geq 0.$$

Data on 1975 and projected 1980 coal consumption by Iowa electric generating utility plants and industrial firms that consumed at least 1,000 tons in 1973 were obtained by mail questionnaires. Data from the questionnaires indicated that about 131 trillion Btu's from coal were consumed in 1975, and 1980 consumption is projected to be 299 trillion Btu's. Sulfur dioxide emission standards were obtained from state and county agencies with pollution control authority [Linn County, Polk County Board of Health, State of Iowa].

Published data on the sources of coal consumed in Iowa in 1976 [U.S. Department of the Interior, 1976] and discussions with an advisory committee of executives from electric utility companies and coal brokerage firms were the basis for selecting the following seven out-of-state coal supply origins: Gillette and Sheridan, Wyoming; Sparta, Canton, and West Harrisburg, Illinois; Nortonville, Kentucky; and Unionville, Missouri.

The annual supply of coal at the Iowa and Missouri sources is limited by mining capacities [Lemish and Sendlein], estimated coal reserves [Avcin], and the expected availability of equipment needed to open new mines. Because Iowa consumes only a small percent of the total production of the six remaining out-of-state coal origins, the supply capacity of these six sources is not constrained in the model.

FOB coal prices as well as sulfur and Btu content of coal from the seven out-of-state origins were obtained from bonded coal bids submitted by coal brokers to electric generating plants from mid-1976 to early-1977 and from the advisory committee. Municipal electric utilities provided similar data for two underground Iowa mines and for five strip mines currently operating in Iowa. Based upon the data on these two underground and five strip mines in Iowa, FOB prices for 24 potential Iowa strip mines [Eldridge] included in the study were estimated by the following equation [Libbin and Boehlje; Nagarvala et. al.].

$$(10)\qquad P = \alpha S^{\beta}$$

where P = estimated price, S = sulfur content in percent of weight, α = constant, and β = regression coefficient.

The following price-sulfur relationship for Iowa strip mine coal was obtained:

$$(11)\qquad P = \$21.12S^{-0.29},\ R^2 = 0.63.$$

These out-of-state and Iowa prices do not include additional mining costs resulting from The Surface Mining Control and Reclamation Act of 1977 [U.S. Congress]. Estimates of additional mining costs resulting from this act were obtained from executives of coal mining companies and were added to the bid and estimated 1977 FOB mine prices.

Iowa coal mine and utility executives agree that these 1977 FOB Iowa mine prices would not allow for the recovery of the total cost of opening and operating the 24 potential Iowa strip mines included in this study and would not encourage the expansion of the Iowa coal mining industry. Therefore, the estimated FOB strip-mine prices, which are based on 1977 prices at existing strip mines, were increased to the estimated average 1977 cost of opening, operating, and reclaiming a new 70,000 ton-per-year mine with an average 50-foot highwall and a 30-inch seam. This cost was estimated to be \$17.33 per ton [Baumel et. al]. The difference between \$17.33 and \$13.48 — the estimated average 1977 FOB mine price — was added to each estimated FOB mine price at each of the 24 potential strip-mine sites in Iowa obtained from Equation 11.

These higher FOB prices also were applied to Missouri strip mine coal because the characteristics of northern Missouri coal are similar to those of Iowa coal. Because Missouri coal mines are larger than Iowa mines, an estimated $1.00 cost savings was subtracted from the price adjustments for opening new mines. The FOB mine coal prices are presented in Table 1.

Coal-beneficiation plant performance data and investment and operating costs were obtained from a "package" beneficiation plant proposed for construction in Iowa and from performance data and costs from an experimental coal beneficiation plant operated by Iowa State University [Grieve et. al]. Annual beneficiation plant capacity of raw coal is estimated to be 840,000 tons. The beneficiation process is estimated to yield 77 percent clean coal and 23 percent refuse, resulting in 646,800 tons of beneficiated coal per year. The process removes about 35 percent of the sulfur and increases the Btu content of the coal by about 12 percent [Grieve and Fisher]. The total investment cost is estimated to be $2,588,000 [Eldridge]. At a 10 percent interest rate, the annual interest and capital recovery is estimated to be $326,413. Other fixed annual costs are estimated to be $350,444 per year. The variable costs of operating the beneficiation plant are estimated to be $0.819 per ton [Eldridge].

Eight sites were selected as potential locations for coal beneficiation plants within a 3½-county coal-producing area in Iowa. The eight sites were restricted to the coal producing area to minimize the distance that refuse must be hauled to the mines for disposal. It was assumed that each site located on rail lines would need 5,800 feet of rail siding; the selected sites had from 0 to 3,360 feet of sid-

TABLE 1. Estimated Btu, Sulfur Content And FOB Mine Coal Prices Based On Coal Bids And On Estimated Iowa Mining And Reclamation Costs, By Coal Origin, 1977

Origin	Btu Per Pound	Percent Sulfur Content	FOB Mine Prices Based On Average Iowa Mining Costs[e]
Sheridan, Wyoming	9,300	0.70	$12.65
Gillette, Wyoming	8,100	0.48	7.65[a]
	8,100	0.48	7.15[a,b]
	8,100	0.48	6.40[c]
Canton, Illinois	11,000	3.25	24.70
Sparta, Illinois	11,400	2.90	22.20
West Harrisburg, Illinois	12,455	1.97	23.35
Nortonville, Kentucky	11,400	2.50	22.33
Unionville, Missouri[d]	10,500	2.62	21.35
Iowa Underground Mines			
Lovilla #4	9,600	2.75	15.72
Big Ben	10,225	4.60	13.53
Potential Iowa Strip Mines			
9 sites	9,794	5.25	16.87
3 sites	9,851	5.33	16.81
4 sites	10,348	5.83	16.47
1 site	10,900	5.60	16.62
1 site	10,181	3.24	18.83
2 sites	10,798	3.11	19.01
2 sites	10,294	5.49	16.70
2 sites	11,549	4.27	17.67

[a]Required annual volume of 500,000-1,500,000 tons.

[b]Shipments in 50- or 100-car trains.

[c]Required annual volume greater than 1,500,000 tons shipped in 100-car trains.

[d]Cleaned coal.

[e]Dollars per ton.

ing. The annualized cost of the additional siding was added to the annual investment cost at each location.

Eight Iowa sites were selected as potential blending locations. Five of the eight sites are located at existing coal-fired steam generating plants. These five locations were selected because the generating plants each use large quantities of coal that, if blended there, would require no transshipment. Moreover, these sites are located relatively close to other coal users and to potential Iowa coal mines, and they would incur relatively low costs to upgrade their facilities to blend coal. The remaining three potential blending sites are potential coal beneficiation sites.

The estimated cost of upgrading utility plants and coal beneficiation plants to blending plants includes the additional investment in equipment to receive, unload, and transfer coal from a 100-car unit train to live coal storage, and the investment in equipment to blend and load-out coal. The facility requirements and the estimated total costs for a blending plant were obtained from data provided by electric utility engineers [O'Riley]. The maximum annual capacity of a blend plant is 3.2 million tons. The estimated total cost of a blending plant is $9,128,800 and the annual interest and capital recovery cost of the total receiving, blending, and load-out investment is $1,068,000. The additional annual investment cost at each of the eight potential coal blending sites was obtained by subtracting the cost of existing usable rail receiving and load-out equipment from the total blending facility costs. The estimated total net annual interest and capital recovery costs at the eight individual potential blending locations ranged from $192,000 to $897,000. The variable cost of blending coal was estimated to be 82.5 cents per ton.

Potential coal blend types must be specified a priori for the model, because the transportation activities are a function of dollars per ton and demand is specified in terms of heating value. Of all the sources of coal considered in the model, Gillette, Wyoming coal yields the lowest SO_2 emissions per million Btu of heat input, while the various Iowa coals yield the highest. Therefore, eight possible minimum blends of Iowa and Gillette, Wyoming coal were specified by the following equation [O'Riley]:

$$(12) \quad K = [(ISO_2)(X) + (WSO_2)(1-X)] \, [(IBtu)(X) + (WBtu)(1-X)]^{-1}$$

where K= sulfur standard: 5, 6, or 8 pounds SO_2 per million Btu; ISO_2 = pounds of SO_2 per ton of Iowa coal; WSO_2 = pounds of SO_2 per ton of Wyoming coal; IBtu = million Btu per ton of Iowa coal; WBtu = million Btu per ton of Wyoming coal; and X = percent of Iowa coal.

A ninth blend consisting of 100-percent Wyoming coal was specified to allow a blending plant to act as a transshipment point. The nine blends, specifying Btu and SO_2 content of blended coal, are minimum blends that will satisfy a user's demand subject to its emission standard. However, these minimum blends do not preclude the possibility of blending Illinois, Missouri, or Kentucky coal with Iowa coal if the minimum Btu content and maximum SO_2 content of the resulting blended coal meet the minimum Btu and maximum SO_2 content of the specified minimum blends.

The rail rates used in the analysis include the actual rates on which coal moved from each out-of-state origin selected in this study to each Iowa coal user during the period from January 7, 1977, to November 30, 1977. These rail rates in effect during this period are referred to as the Ex Parte 336 rates and were primarily for single-car rail shipments. Only a few coal users had access to multiple-car or unit-train shipments from the selected coal origins at the time of this analysis. Therefore, rates were estimated for 15-car, 50-car, and 100-car rail shipments for origins and destinations that did not have published rates for these shipment sizes. The estimated 15-car, 50-car, and 100-car rates were calculated from a rail-cost computer program designed to estimate variable rail costs [Baumel, et. al]. These estimated variable costs were converted to estimated rates by multiplying the estimated variable cost by a ratio consisting of published Ex Parte 336 rates for the same size shipments to different destinations divided by the estimated variable costs to those destinations.

Trucking cost functions, using mid-1977 cost levels, were estimated for hauling coal from mines to users, blending plants, and beneficiation plants, from blending and beneficiation plants to users, and for hauling beneficiation refuse to mines for disposal [Eldridge]. The estimated cost function for hauling coal from mines to beneficiation plants and for hauling refuse from the plants to the mines is C_t = \$0.1743 + \$0.0578 m, where C_t = cost per ton and m = loaded miles. Refuse was not permitted to be a backhaul because of the difficulty of cleaning the refuse sludge from the truck after each load. The estimated cost functions for hauling coal from the mine, beneficiation plant or blending plant to users under the 73,280-pound truck gross weight limit were:

Loaded Miles	Cost Functions
0 - 20	C_t = \$0.3668 + \$0.0414 m
20.1 - 75	C_t = 0.3711 + 0.0411 m
75.1 - 200	C_t = 0.7439 + 0.0360 m

Assuming a 15 percent profit margin, trucking rate functions were estimated from the trucking cost estimates by multiplying each trucking cost function by 1.15.

Data on the cost of combined rail-barge movements to Iowa destinations on the Mississippi River from Sparta and West Harrisburg, Illinois and from Nortonville, Kentucky were obtained from coal mining and barge companies.

Data on the 1977 rail receiving capacity were obtained from each major electric generating utility and industrial coal user in Iowa. Estimates were made of the cost of upgrading the rail receiving capacity of each coal user to the next larger size of rail shipment. If the facility could receive 100-car unit trains, no additional investment in rail receiving capacity was permitted. The variable cost of receiving, unloading, and transferring the coal to live storage by mode and size of shipment was obtained from utility company executives.

Findings

Two model solutions are presented. One solution, the "blending solution", determines the optimal number and location of coal blending plants in Iowa as well as the optimal amount of coal shipped from each origin and from each blending or beneficiation plant to each coal-using location, the optimal mode of transport, the optimal number and location of coal-beneficiation plants, and specifies which Iowa coal users should increase their rail receiving capacity. A second solution, the "beneficiating solution", differs from the first solution only in that coal blending is not permitted. The comparison of these solutions provides the basis for evaluating the impact of mechanical coal blending on the utilization of low-sulfur Wyoming and high-sulfur Iowa coal.

The amount of coal consumed in Iowa by coal origin under the two solutions is presented in Table 2. Wyoming would supply nearly 14 million tons under the blending solution compared with 11 million tons under the beneficiation solution. Illinois would supply more than 2 million tons under the blending solution compared with nearly 4.5 million tons under the beneficiation solution. Iowa underground coal would remain at 307,290 tons under both solutions. Raw Iowa strip mine coal production would be 1,299,000 tons under the blending solution compared with 840,000 tons under the beneficiation solution. No Iowa coal would be beneficiated under the blending solution while all the Iowa strip mine coal produced under the beneficiation solution would be beneficiated.

The estimated total cost of supplying Iowa's 1980 projected coal consumption under the blending solution is \$320.7 million while the estimated total cost under the beneficiation solution is \$328.0 million. Thus, the estimated total cost of supplying Iowa's 1980 projected coal consumption would decrease by \$7.3 million if Iowa and Wyoming coal

TABLE 2. Estimated 1980 Iowa Coal Consumption By Coal Origin

	Blending Solution		Beneficiation Solution	
Coal Origin	Tons	Percentage	Tons	Percentage
Wyoming	13,727,978	78.4	11,096,220	67.4
Illinois	2,182,461	12.5	4,419,560	26.8
Kentucky	0	0	0	0
Missouri	0	0	0	0
Iowa				
Underground	307,290	1.7	307,290	1.9
Strip	1,299,000	7.4	646,800[a]	3.9
	17,516,729	100.0	16,469,870	100.0

[a]840,000 tons of raw coal are required to yield 646,800 tons of beneficiated coal.

were blended at central points in Iowa and then transshipped to coal users in Iowa.

Under the blending solution, blending plants would be constructed at four locations (Figure 1). More than 5.5 million tons of coal (Table 3), or about one-third of Iowa's projected 1980 coal consumption, would move through blending plants. Wyoming coal would be shipped to these plants in 100-car unit trains. Raw Iowa strip mine coal would be shipped to blending plants by truck.

Table 4 presents the tons of coal transported from blending plants to coal users in Iowa under the blending solution. Only seven of nine possible blends were utilized.

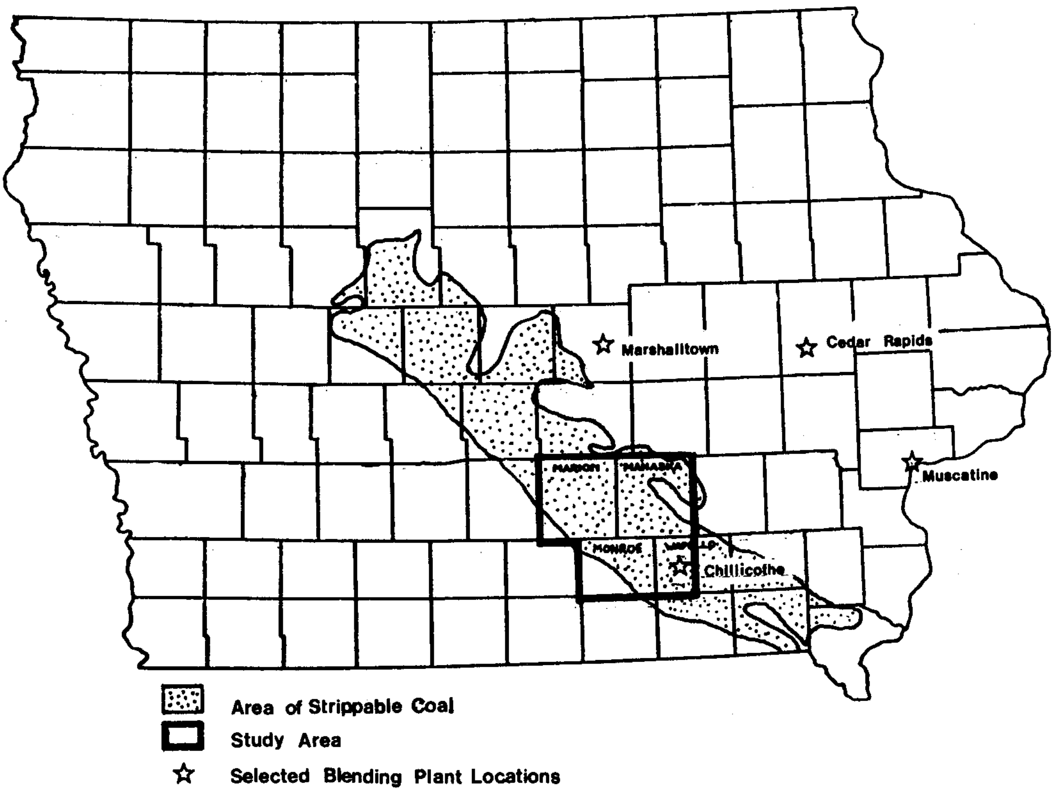

Figure 1. Locations Of 3½-County Coal Producing Area And Selected Blending Plant Location Under The Blending Solution, Iowa, 1980.

TABLE 3. Estimated Quantity Of Iowa And Wyoming Coal Received By Iowa Blending Plants Under The Blending Solution In Tons, 1980

Iowa Blending Plant Location	Origin		Total
	Iowa Strip Mine	Wyoming	
Marshalltown	300,862	1,408,429	1,709,291
Chillicothe	869,403	212,095	1,081,498
Cedar Rapids	0	1,507,185	1,507,185
Muscatine	128,735	1,123,112	1,251,847
TOTAL	1,299,000	4,250,821	5,549,821

Approximately 3.5 million tons of coal received by users from blending plants would be unblended Wyoming coal; 2.1 million tons of this coal would be used by the utility plants selected as blending sites, and the remaining 1.4 million tons would be transshipped to Iowa users. The remaining 2 million tons of coal shipped from blending plants would contain 45 to 88 percent raw Iowa strip-mine coal. Nearly two-thirds of the coal shipped from the four blending plants would be Wyoming coal received in 100-car train shipments and distributed in smaller shipments to other Iowa users. The remaining one-third of the coal shipped from blending plants to other Iowa users would be a blend of raw Iowa strip-mine coal and Wyoming coal.

Table 5 presents the distribution of coal by SO_2 emission standard. Iowa underground mine coal would be shipped to users with 5-pound and 8-pound standards. Users with the 1.2-pound SO_2 standard would receive only unblended Wyoming coal. Users with the 5-pound standard would receive 71 percent of their coal from blending plants, 6-pound users would receive 53 percent of their coal from blending plants, and 8-pound users would receive almost 94 percent of their coal from blending plants.

Conclusions and Implications

There were a number of major findings and implications of this analysis.

1. Blending raw Iowa strip mine coal with Wyoming coal would increase both Iowa high-sulfur coal production and Wyoming coal production. Estimated 1980 raw Iowa strip mine coal production would increase from 840,000 tons in the beneficiation solution — which precludes the possibility of blending — to 1,299,000 tons under the blending solution. The amount of Wyoming coal consumed in Iowa in 1980 under the blending solution would increase from about 11,000,000 tons to about 13,700,000 tons.
2. The largest market for coal from blending plants consists of users with the 6-pound SO_2 emission standard. How-

TABLE 4. Estimated Quantity Of Coal Shipped From Blenders To Users In Iowa By Type Of Blend Under The Blending Solution In Tons, 1980

Blend Percentage		Tons	Percent Of Total
Iowa	Wyoming		
70.7	29.3	369,384	6.7
87.5	12.5	161,223	2.9
45.7	54.3	612,829	11.0
67.4	32.6	156,264	2.8
45.0	55.0	76,058	1.4
69.0	31.0	652,356	11.7
0.0	100.0	3,521,707	63.5
TOTAL		5,549,821	100.0

TABLE 5. Estimated Iowa Coal Consumption By SO_2 Emission Level And Coal Origin Under the Blending Solution, 1980

SO_2 Emission Standard In Pounds Per Million Btu	Received From Underground Iowa Mines		Received From Out-Of-State Mines		Received From Blending Plants		Total	
	Tons	Percentage	Tons	Percentage	Tons	Percentage	Tons	Percentages
1.2	0		9,219,040	100.0	0		9,219,040	100.0
5	186,417	9.6	376,543	19.3	1,386,617	71.1	1,949,577	100.0
6	0		2,064,035	46.9	2,339,693	53.1	4,403,728	100.0
8	120,873	6.2	0		1,823,511	93.8	1,944,384	100.0
TOTAL	307,290		11,659,618		5,549,821		17,516,729	

ever, users with 5- and 8-pound SO_2 emission standards would also consume significant quantities of coal from blending plants. Many coal users with 5- to 8-pound emission standards are smaller electric generating utilities or industrial firms. The smaller users would consume very little low-sulfur western coal under the beneficiation solution. Thus, the blending alternative would allow producers of low-sulfur western coal to provide a significant share of the coal for smaller coal users. This increased western coal would be substituted for Illinois coal.

3. The blending plants could be considered as transshipment points in that they receive low-priced Wyoming coal in 100-car unit trains and distribute the Wyoming coal in smaller shipment sizes to the Iowa users. Only one-third of the coal shipped from blending plants would be a blend of raw Iowa strip mine coal and Wyoming coal. The transshipment concept would allow producers of low-sulfur western coal to provide larger amounts of coal to smaller coal users in other consuming states, even if the other states had no coal reserves to blend with the western coal.
4. The blending solution would reduce the estimated cost of supplying the 1980 Iowa projected coal consumption by $7.3 million compared with the beneficiation solution. The reason for this large reduction is the large increase in the amount of Wyoming coal that would be purchased at lower FOB prices and shipped in low-cost 100-car unit trains. The $7.3 million cost reduction, which would accrue to consumers of electricity from utilities that buy blended coal, would result in a cost saving on electricity of about $9.40 per year for a residential consumer using about 650 kilowatts per month.
5. The increased strip mine coal production in Iowa would result in an increase in coal lease income to owners of rural

land. The impact of the increased strip mining on agricultural production and income is unclear. First, the most accessible coal deposits in Iowa are located on land that is generally unsuited for row crop production. Second, the three and one-half county study area in Iowa has a relatively small proportion of its land in crop production. In 1977, less than 60 percent of the land in this area that was not under towns, water, or roadways was in crop production. Third, the Surface Mining Control and Reclamation Act of 1977 [U.S. Congress] requires that strip-mined land be reclaimed to at least the level of productivity that existed prior to the strip mining. An experimental mine operated by Iowa State University in the study area has been reclaimed with a minimum of four feet of subsoil and one foot of topsoil. The reclaimed topography is more suitable for crop production than the original topography, but there has been a loss of soil structure. The plots are in the first year of row crop production and the effects of strip mining on agricultural production will not be known until time and root growth can restore the soil structure.

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